Bacteria TMDLs for the Hunting Creek, Cameron Run, and Holmes Run Watersheds

DRAFT REPORT

Submitted by:

Virginia Department of Environmental Quality

Prepared by:

Interstate Commission on the Potomac River Basin

July 19, 2010

Table of Contents

List of Figures

List of Tables

List of Acronyms

ARA	Antibiotic Resistance Analysis
ASA	Alexandria Sanitation Authority
BMP	Best Management Practices
BST	Bacterial Source Tracking
CBPO	Chesapeake Bay Program Office
cf/yr	Cubic Feet per Year
CFL	Courant-Friedrichs-Lewy
CFR	Code of Federal Regulations
cfs	Cubic Feet per Second
cfu	Colony Forming Units
COA	City of Alexandria
CSO	Combined Sewer Overflows
CSS	Combined Sewer Systems
CV	Coefficient of Variation
DC DOE	District of Columbia Department of the Environmental
DCIA	Directly Connected Impervious Area
DCR	Department of Conservation and Recreation
DC WASA	District of Columbia Washington Water and Sewer Authority
DEM	Digital Elevation Model
DMME	Department of Mines, Minerals, and Energy
DMR	Discharge Monitoring Report
E. coli	*Escherichia Coli*
ELCIRC	Euler-Lagrangian Circulation
EOS	Edge-of-Stream
EPA	Environmental Protection Agency
FEMA	Federal Emergency Management Agency
GIS	Geographic Information System
HEC-RAS	Hydrologic Engineering Centers River Analysis System
HSPF	Hydrological Simulation Program Fortran
ICPRB	Interstate Commission on the Potomac River Basin
IP	Implementation Plan
LA	Load Allocation
LTA	Long-Term Average
LTCP	Long-Term Control Plan
LTI	Limno-Tech, Inc.
MDL	Maximum Daily Limit
MGD	Million Gallons per Day
MHHW	Mean Higher High Water Level
mL	Milliliter
MLLW	Mean Lower Low Water Level
MOS	Margin of Safety
MS4	Municipal Separate Storm Sewer
NAVD88	North American Vertical Datum of 1988
NCDC	National Climatic Data Center
NHD	National Hydrography Dataset
NMCs	Nine Minimum Controls
NOAA	National Oceanic and Atmospheric Administration

NPDES	National Pollution Discharge Elimination System
NRCS	Natural Resources Conservation Service
NVRC	Northern Virginia Regional Commission
P52	Phase 5.2 Watershed Model
QA/QC	Quality Assurance / Quality Control
SSO	Sanitary Sewer Overflows
SSURGO	Soil Survey Geographic Database
STATSGO	State Soil Geographic
SWCB	State Water Control Board
SWCD	Soil and Water Conservation District
SWMM	Storm Water Management Model
TAC	Technical Advisory Committee
TMDL	Total Maximum Daily Load
UAA	Use Attainability Analysis
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
VADEQ	Virginia Department of Environmental Quality
VDGIF	Virginia Department of Game And Inland Fisheries
VDH	Virginia Department of Health
VDOT	Virginia Department of Transportation
VIMS	Virginia Institute of Marine Science
VPDES	Virginia Pollutant Discharge Elimination System
VSMP	Virginia Stormwater Management Program
WID	Watershed Improvement District
WLA	Wasteload Allocation
WQIF	Water Quality Improvement Fund
WQMIRA	Water Quality Monitoring, Information, and Restoration Act
WQMP	Water Quality Management Plan
WQS	Water Quality Standard
WWF	Wet Weather Flow
WWTP	Wastewater Treatment Plant

Executive Summary

This report presents the development of bacteria TMDLs for three Northern Virginia waterbodies: (1) Holmes Run (2004 TMDL ID: VAN-A13R-02); (2) Cameron Run (2006 TMDL ID: 60029); and (3) Cameron Run /Hunting Creek (2004 TMDL ID: VAN-A13E-02).

Hunting Creek was listed as impaired for bacteria in Virginia's 2008 305(b)/303(d) Water Quality Assessment Integrated Report (VADEQ, 2008) due to exceedances of the state's water quality criteria for *E. coli* bacteria. The segment was first listed as impaired for fecal coliform bacteria on Virginia's 1998 303(d) List, and was included in Attachment A of the 1999 Consent Decree.

Cameron Run (listed as "Cameron Run/Hunting Creek" in the 2008 Integrated Assessment, but referred to as "Cameron Run" in this report) was listed as impaired for bacteria in Virginia's 2008 305(b)/303(d) Water Quality Assessment Integrated Report (VADEQ, 2008) due to exceedances of the state's water quality criteria for *E. coli* bacteria. The segment was first listed as impaired for *E. coli* bacteria on Virginia's 2006 Integrated List.

Holmes Run was listed as impaired for bacteria in Virginia's 2008 305(b)/303(d) Water Quality Assessment Integrated Report (VADEQ, 2008) due to exceedances of the state's water quality criteria for *E. coli* bacteria. The segment was first listed as impaired for fecal coliform bacteria on Virginia's 2004 Integrated List.

Description of the Study Area

All three impaired segments are located within the Potomac River basin (USGS Cataloging Unit 02070010) in the City of Alexandria and Fairfax County, Virginia. The impaired segment of Holmes Run extends from the confluence of Holmes Run and Backlick Run upstream to the mouth of Lake Barcroft, covering approximately 3.58 miles. The impaired segment of Cameron Run extends from the head of tide at approximately the Route 611/241 (Telegraph Road) bridge crossing, upstream to the confluence of Holmes Run and Backlick Run, covering approximately 2.08 miles. The impaired segment of Hunting Creek extends from the confluence with the Potomac River at the state boundary, to the upstream limit of tidal waters at the Route 611/241 (Telegraph Road) bridge crossing, covering approximately 0.526 mi^2.

Impairment Description

During the 2008 assessment period (January 2001 through December 2006), 25% or more of the samples collected at monitoring stations on all three impaired segments exceeded the *E. coli* maximum criterion of 235 cfu/100 ml: 3 out of 12 *E. coli* samples (25.0%) collected at listing station 1AHOR001.04 on Holmes Run, 5 out of 18 *E. coli* samples (27.8%) collected at listing station 1ACAM002.92 on Cameron Run, 11 out of 27 *E. coli* samples (40.7%) collected at listing station 1AHUT000.01 in Hunting Creek, and 3 out of 11 *E. coli* samples (27.3%) collected at listing station 1AHUT001.72 on Hunting Creek, exceeded the *E. coli* maximum criterion of 235 cfu/100 ml.

Applicable Water Quality Standards

At the time of the initial listing of Hunting Creek (VAN-A13E-02), the Virginia Bacteria Water Quality Criteria was expressed in fecal coliform bacteria; however, the bacteria water quality criteria was subsequently changed and is now expressed in *E. coli*. Virginia's bacteria water quality criteria currently states that *E. coli* bacteria shall not exceed a geometric mean of 126 *E. coli* counts per 100 mL of water for four or more weekly samples within a calendar-month. If there are insufficient samples to calculate the calendar-month geometric mean, no more than 10% of the total samples in an assessment period can exceed an *E. coli* concentration of 235 counts per 100 mL.

The loading rates for watershed-based modeling are available only in terms of the previous criteria, fecal coliform bacteria. Therefore, the TMDL was expressed in *E. coli* by converting modeled daily fecal coliform concentrations to daily *E. coli* concentrations using an instream translator. As of the approval of the latest revisions to Virginia's Water Quality Standards (February 1, 2010), bacteria TMDLs in Virginia are developed only to meet the geometric mean criteria. Prior to the most recent change in the water quality standards, bacteria TMDLs in Virginia were developed to meet both the geometric mean and the instantaneous maximum criteria, formerly 235 counts per 100 ml. This change is noteworthy as the standard change occurred during development of the TMDL.

Watershed Characterization

The land use characterization for the watersheds of the impaired segments was based on land use data provided by the City of Alexandria, the City of Falls Church, Fairfax County, and the Army Corps of Engineers. There is no agriculture in the watershed. Approximately 12% of the watershed is made up of parks, golf courses, or open space. The rest of the watershed is developed. Potential key sources of bacteria include pets, wildlife, failing septic systems, and sanitary sewer cross-connections, spills, or leaks.

There are two facilities in the Hunting Creek watershed that hold active, individual, municipal Virginia Pollutant Discharge Elimination System (VPDES) permits. These permits are issued through the VPDES permitting program and are authorized to discharge the pollutant of concern for this TMDL. The Alexandria Sanitary Authority's Advanced Wastewater Treatment Plant is a major municipal wastewater treatment plant permitted to discharge into Hunting Creek at a maximum rate of 54 million gallons per day (MGD). The City of Alexandria's Combined Sewer System (CSS) is permitted to discharge through four outfalls, three of which discharge to waters included in this TMDL study: Outfall 002 into Hunting Creek and Outfalls 003 and 004 into Hooff Run, a tributary to Hunting Creek. In addition, there are two other minor individual, industrial VPDES permits and several general VPDES permits issued for industrial stormwater within the Hunting Creek watershed; however, none of these are recognized to discharge the pollutant of concern.

Fairfax County, Arlington County, the City of Alexandria, the City of Falls Church, the Virginia Department of Transportation, Fairfax County Public Schools, and the George Washington Memorial Parkway hold municipal separate storm sewer system (MS4) permits in the watershed of the impaired segments.

TMDL Technical Approach

A Hydrologic Simulation Program-Fortran (HSPF) model was developed to cover the entire drainage to Hunting Creek, including Cameron Run and Holmes Run. This model, the Cameron Run HSPF Model, was used both to develop the bacteria TMDLs for Holmes Run and Cameron Run and to provide input loads from non-point sources for the tidal Hunting Creek bacteria TMDL. HSPF is the standard model used in Virginia TMDLs to simulate the fate and transport of bacteria in watersheds.

The Cameron Run HSPF Model simulated as many as seven land uses in 19 subwatersheds. Nine of the watersheds were upstream of the head-of-tide on Cameron Run; the tidal influence of Hunting Creek extends upstream approximately to Telegraph Road. One of the upstream segments of the

Cameron Run model represented Lake Barcroft. The remaining 10 subwatersheds represented small tributaries like Hooff Run or Quander Creek, or direct drainage to tidal waters. The calibration period for the model was 2001 -2005 with a verification period of 1996-2000.

The hydrology simulation was calibrated against daily average flows observed at the United States Geological Survey (USGS) gage 01653000 on Cameron Run at Alexandria, VA. Simulated flows were within the standard tolerance limits reported in Virginia TMDLs, with a coefficient of determination (R^2) between observed and simulated daily average flows of 0.76 over the calibration period.

Like most other Virginia TMDLs, the Cameron Run HSPF Model simulated fecal coliform bacteria. The bacteria simulation was calibrated against monitoring data from three VADEQ monitoring stations (1AHOR001.04 on Holmes Run, 1ABAL001.40 on Backlick Run, and 1ACAM002.92 on Cameron Run) and two City of Alexandria monitoring stations (BSL-4 on Hooff Run and BSL-5 on Cameron Run.) The model was calibrated primarily by adjusting the in-stream bacteria decay rate, the maximum storage of bacteria on the land surface, and the rate at which bacteria are washed off the land surface. The geometric mean of the simulated bacteria concentrations and the simulated rate at which the maximum bacteria criterion were exceeded at a station agreed with their observed counterparts when the distribution of observed data, which is weighted more heavily toward storm events at the City of Alexandria's monitoring stations, is taken into account.

HSPF is not capable of simulating tidal waterbodies. The Euler-Lagrangian Circulation (ELCIRC) model was chosen to simulate the hydrodynamics and fate and transport of bacteria in tidal Hunting Creek. ELCIRC is a two- or three- dimensional continuous simulation model developed to represent the hydrodynamics and water quality of tidal waters such as embayments, estuaries, or waters off the continental shelf. It uses a semi-implicit finite-difference, finite-volume approach to solve shallow water equations on an orthogonal unstructured grid. An Euler-Lagrangian advection scheme is used to solve the momentum and water quality equations to overcome the limitations of the Courant-Friedrichs-Lewy condition. This allows ELCIRC to represent relatively small grid sizes using a relatively large time step. ELCIRC is also capable of representing the dynamics of wetting and drying in tidal flats which occur in Hunting Creek.

The domain of the Hunting Creek ELCIRC Model was extended to include portions of the Potomac River upstream and downstream of its confluence with Hunting Creek, in order to better simulate the exchange of flows and bacteria between the Potomac River and Hunting Creek. The domain includes over 14,000 cells and 4,500 nodes arranged in two and three-sided polygons. The spatial resolution of the model in the lateral direction is 30-50 meters and in the horizontal direction is 50-90 meters.

ELCIRC's hydrodynamic simulation was calibrated by adjusting the Chezy coefficient until simulated surface water elevations agreed with observations from the USGS station 0165258890 at the Cameron Street Dock in Alexandria, VA. The hydrodynamic calibration was verified by comparing simulated surface water elevations to synthetic astronomical tides generated at four locations in the model domain.

ELCIRC's bacteria simulation was calibrated against observed data collected by VADEQ at monitoring station 1AHUT000.01 and by the City of Alexandria at three stations (BSL-1, BSL-2, and BSL-3) where bacteria is monitored as part of its CSS permit. In addition, the District of Columbia's water quality monitoring station PMS44 was also used in the calibration. The ELCIRC model was calibrated by adjusting the bacteria decay coefficient until the distribution of simulated concentrations matched the distribution of observed data at each station, as shown by a comparison of Box-and-Whisker plots. The calibrated value of the decay rate was 0.1 /day.

Both the HSPF and the ELCIRC models are continuous simulation models. Over the course of the simulation period, 2004 through 2005, which was used to set the TMDLs, seasonal variations and a variety of hydrological conditions were simulated, covering a range of potential critical conditions for meeting water quality standards in Holmes Run, Cameron Run, and Hunting Creek.

TMDL Calculations

The TMDL represents the maximum amount of a pollutant that a stream can receive without exceeding the water quality standard. The bacteria allocations for the selected TMDL scenario were calculated using the following equation:

$$TMDL = \sum WLA + \sum LA + MOS$$

Where:

WLA = wasteload allocation (point source contributions)
LA = load allocation (non-point source allocation)
MOS = margin of safety

The margin of safety (MOS) is a required component of the TMDL to account for any lack of knowledge concerning the relationship between effluent limitations and water quality. The MOS was implicitly incorporated in this TMDL through use of conservative assumptions and approaches, including those used to compute source bacteria loadings as well as to establish boundary conditions (See section 5.1 for an extended discussion on the MOS).

Since both the HSPF model and the ELCIRC model simulate fecal coliform bacteria, VADEQ's translator equation was used to compare simulated fecal coliform bacteria concentrations to the *E. coli* criterion:

E. coli conc. (cfu/100 mL) = 2-0.0172 x [fecal coliform conc. (cfu/100mL)] 0.91905

To arrive at the proposed TMDL scenarios for Holmes Run and Cameron Run, and to derive the TMDL loading capacity for tidal Hunting Creek, the calibrated HSPF model was first used to test whether potential TMDL scenarios would meet water quality standards for bacteria. For all scenarios, it was assumed that bacteria from human sources such as failing septic systems and sanitary sewer overflows would be reduced by 100%, since such sources are not authorized to discharge. Each scenario was then specified by determining a level of reduction for (1) direct deposition of bacteria by wildlife and (2) land-based edge-of-stream (EOS) bacteria loads, which include contributions from both wildlife and pets. Using the Cameron Run HSPF Model, it was determined that an 83% reduction in EOS bacteria loads and a 50% reduction in direct deposition of bacteria into streams would enable both Holmes Run and Cameron Run to meet water quality standards. The bacteria TMDLs for Holmes Run, in terms of a daily and annual load, are presented in Tables E-1 and E-2. The bacteria TMDLs for Cameron Run, in terms of a daily and annual load, are presented in Tables E-3 and E-4.

Table ES-1: Holmes Run TMDL (cfu/day) for *E. coli* Bacteria

WLA	LA	MOS	TMDL
2.56E+11	2.74E+10	Implicit	2.83E+11

Table ES-2: Holmes Run TMDL (cfu/year) for *E. coli* Bacteria

WLA	LA	MOS	TMDL
8.38E+13	8.99 E+12	Implicit	9.28E+13

Table ES-3: Cameron Run TMDL (cfu/day) for *E. coli* Bacteria			
WLA	**LA**	**MOS**	**TMDL**
4.40E+11	6.54E+10	Implicit	5.05E+11

Table ES-4: Cameron Run TMDL (cfu/year) for *E. coli* Bacteria			
WLA	**LA**	**MOS**	**TMDL**
1.33E+14	1.98 E+13	Implicit	1.53E+14

The calibrated Hunting Creek ELCIRC model was used to test whether potential TMDL scenarios would meet water quality standards for bacteria in the tidal waters of the Hunting Creek watershed. The following conditions were applied for all potential TMDL scenarios:

1. The Alexandria Sanitation Authority's Advanced Wastewater Treatment Plant was simulated at its current design flow of 54 MGD, with an additional 12 MGD for future growth, and at the fecal coliform concentration of 195 cfu/ 100 ml, equivalent to 126 cfu/100 ml of *E. coli*. This equates to meeting the bacteria criterion of the Virginia Water Quality Standards at the point of discharge consistent with the VPDES permit for the facility.

2. Cameron Run was simulated with the bacteria load reductions under the TMDL scenario meeting water quality standards in Holmes Run and Cameron Run.

3. Small tributaries and direct drainage to tidal Hunting Creek were simulated at the levels of reduction of bacteria loads which meet water quality standards as determined by the HSPF simulations of Cameron Run and Hooff Run.

Under all TMDL scenarios, the model domain boundaries upstream and downstream on the tidal freshwater Potomac River were set at a constant fecal coliform concentration of 195 cfu/ 100 ml, equivalent to the monthly geometric mean criterion for *E. coli* bacteria (126 cfu/100ml).

In arriving at the final proposed TMDL condition, two approaches were considered for establishing the boundary of the Hunting Creek embayment with the Potomac River. Both of these approaches apply the assumption that all sources within the overall model domain, but outside of the Hunting Creek watershed, meet water quality standards at their point of discharge. This general approach requires the sources within the Hunting Creek watershed to meet water quality standards in the impaired segment by themselves, without relying on significant dilution from the Potomac River achieved by reductions from sources outside of the impaired waterbody. As the model domain includes portions of Maryland and the District of Columbia, this approach does not impose reductions from sources in other jurisdictions beyond those required to meet their own water quality standards.

The difference between the two approaches considered in establishing the boundary of the Hunting Creek embayment with the Potomac River is the bacteria decay rate applied to the mainstem of the Potomac River outside of Hunting Creek. Two different decay rates were used in the Potomac River portion of the model domain: (1) a decay rate of 0.0 /day, which effectively set the boundary of the impairment at approximately the fecal coliform equivalent of the *E. coli* criterion (i.e. 195 cfu/100 ml), and (2) the calibrated decay rate of 0.1/day. The calibrated bacteria decay rate of 0.1/day was used in the tidal Hunting Creek portion of the model domain under all scenarios.

Given these conditions, potential TMDL scenarios differed from each other primarily in the level of reduction required from the City of Alexandria's CSS. Different levels of reduction were applied to Outfall 002 and Outfalls 003 and 004, to take into account the effect of their discharge location on meeting water quality standards. Because of the fine-scale resolution of the ELCIRC model, the Hunting Creek impairment was divided into two assessment areas to determine attainment with water quality standards. The first is upstream of the George Washington Memorial Parkway (GW Parkway); the second is downstream from the GW Parkway, occupying the Hunting Creek embayment adjacent to the Potomac River. The daily average bacteria concentration was averaged over each of these assessment areas before the simulated concentrations were compared to the monthly geometric mean criterion.

Using the calibrated ELCIRC model, it was determined that a 99% reduction in bacteria loads from CSO outfalls 003 and 004 would be required to meet water quality standards under the conditions specified above. An 85% reduction in bacteria loads from CSO outfall 002 would be required to meet water quality standards if a decay rate of 0.0/day was used to set the boundary condition; otherwise, an 80% reduction would be required if the Potomac River decay rate was set at 0.1/day. The latter scenario was chosen to set the TMDL allocations.

The bacteria TMDLs for tidal Hunting Creek, in terms of a daily and annual load, are presented in Tables E-5 and E-6.

Table ES-5: Hunting Creek TMDL (cfu/day) for *E. coli* Bacteria			
WLA	**LA**	**MOS**	**TMDL**
2.09E+12	1.90E+11	Implicit	2.28E+12

Table ES-6: Hunting Creek TMDL (cfu/year) for *E. coli* Bacteria			
WLA	**LA**	**MOS**	**TMDL**
3.24E+14	2.23 E+13	Implicit	3.46E+14

TMDL Implementation

Once a TMDL is approved by EPA, measures must be taken to reduce pollutant levels from both point and non-point sources. For non-point sources, the Commonwealth intends for reductions required for this TMDL to be implemented, and pollutant loading reductions achieved, through best management practices (BMPs). Permitted point sources of bacteria, including MS4 and VPDES permits will achieve any required reductions through incorporating the TMDL results into existing permits through their respective permit programs.

Implementation for both point and non-point sources will occur in stages. The benefits of staged implementation are: 1) as stream monitoring continues to occur, it allows for water quality improvements to be recorded as they are being achieved; 2) it provides a measure of quality control, given the uncertainties that exist in any model; 3) it provides a mechanism for developing public support; 4) it helps to ensure the most cost effective practices are implemented initially, and 5) it allows for the evaluation of the TMDL's adequacy in achieving the water quality standard.

While section 303(d) of the Clean Water Act and current EPA regulations do not require the development of TMDL implementation plans as part of the TMDL process, they do require reasonable assurance that the load and waste load allocations can and will be implemented. Additionally, Virginia's 1997 Water Quality Monitoring Information and Restoration Act (WQMIRA) directs the State Water Control Board to "develop and implement a plan to achieve fully supporting status for impaired waters" (Section 62.1-44.19.7). WQMIRA also establishes that the implementation plan shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated costs, benefits and environmental impacts of addressing the impairments. EPA outlines the minimum elements of an approvable implementation plan in its 1999 "Guidance for Water Quality-Based Decisions: The TMDL Process." The listed elements include implementation actions/management measures, timelines, legal or regulatory controls, time required to attain water quality standards, monitoring plans, and milestones for attaining water quality standards.

As part of the Continuing Planning Process, VADEQ staff will present EPA-approved TMDLs and TMDL implementation plans to the State Water Control Board (SWCB) for inclusion in the appropriate Water Quality Management Plan (WQMP), in accordance with the Clean Water Act's Section 303(e) and Virginia's Public Participation Guidelines for Water Quality Management Planning. VADEQ staff will also request that the SWCB adopt TMDL WLAs as part of the Water Quality Management Planning Regulation (9VAC 25-720), except in those cases when permit limitations are equivalent to numeric criteria contained in the Virginia Water Quality Standards, such as in the case for bacteria discharges resulting from treatment of municipal and industrial wastewater.

Implementation of the TMDL for the City of Alexandria's Combined Sewer System will be accomplished through the VPDES permit. The reissuance of the permit will reflect the provisions of the TMDL, and will be done in accordance with EPA's CSO Control Policy.

1 Introduction

1.1 Regulatory Guidance

Section 303(d) of the Clean Water Act and the Environmental Protection Agency's (EPA's) Water Quality Planning and Management Regulations (40 CFR Part 130) require states to develop Total Maximum Daily Loads (TMDLs) for water bodies that are exceeding water quality standards. TMDLs represent the total pollutant loading that a waterbody can receive without exceeding water quality standards. The TMDL process establishes the allowable loadings of pollutants for a waterbody based on the relationship between pollution sources and instream water quality conditions. By following the TMDL process, states can establish water quality based controls to reduce pollution from both point and non-point sources to restore and maintain the quality of their water resources (EPA, 2001).

The Virginia Department of Environmental Quality (VADEQ) is the lead agency for the development of TMDLs statewide and focuses its efforts on all aspects of reduction and prevention of pollution to state waters. VADEQ works in coordination with the Virginia Department of Conservation and Recreation (DCR), the Department of Mines, Minerals, and Energy (DMME), and the Virginia Department of Health (VDH) to develop and regulate a more effective TMDL process. VADEQ ensures compliance with the Federal Clean Water Act and the Water Quality Planning Regulations, as well as with the Virginia Water Quality Monitoring, Information, and Restoration Act (WQMIRA), passed by the Virginia General Assembly in 1997, and coordinates public participation throughout the TMDL development process.

Within the context of the TMDL program, a primary role of DCR is to regulate stormwater discharges from construction sites, and from municipal separate storm sewer systems (MS4s) through the Virginia Stormwater Management Program (VSMP). Another important role of DCR is to initiate non-point source pollution control programs statewide through the use of federal grant money. DMME focuses its efforts on issuing surface mining permits and National Pollution Discharge Elimination System (NPDES) permits for industrial and mining operations. Lastly, VDH monitors waters for fecal coliform, classifies waters for shellfish growth and harvesting, and conducts surveys to determine sources of bacterial contamination (VADEQ, 2001).

As required by the Clean Water Act and WQMIRA, VADEQ develops and maintains a listing of all impaired waters in the state that details the pollutant(s) causing each impairment and the potential source(s) of each pollutant. This list is referred to as the 303(d) List of Impaired Waters. In addition to 303(d) List development, WQMIRA directs VADEQ to develop and implement TMDLs for listed waters (VADEQ, 2001a). Once TMDLs have been developed, they are distributed for public comment and then submitted to the EPA for approval.

1.2 Impairment Listings

The following impairment listings are addressed in this report:

Hunting Creek (2004 TMDL ID: VAN-A13E-02) was listed as impaired for bacteria in Virginia's 2008 305(b)/303(d) Water Quality Assessment Integrated Report (VADEQ, 2008) due to exceedances of the state's water quality criteria for *E. coli* bacteria. The segment was first listed as impaired for fecal coliform bacteria on Virginia's 1998 303(d) List, and was included in Attachment A of the 1999 Consent Decree. The impaired segment is located within the Potomac River basin (USGS Cataloging Unit 02070010) in the City of Alexandria and Fairfax County, Virginia (**Figure 1-1**).

The impaired segment of tidal Hunting Creek extends from the confluence with the Potomac River at the state boundary, to the upstream limit of tidal waters at the Route 611/241 (Telegraph Road) bridge crossing, covering approximately 0.526 mi^2. During the 2008 assessment period (January 2001 through December 2006), 11 out of 27 *E. coli* samples (40.7%) collected at listing station 1AHUT000.01 exceeded the *E. coli* maximum criterion of 235 cfu/100 ml, and 3 out of 11 *E. coli* samples (27.3%) collected at listing station 1AHUT001.72 exceeded the *E. coli* maximum criterion of 235 cfu/100 ml. Station 1AHUT000.01 is located at the George Washington Memorial Parkway bridge crossing, and Station 1AHUT001.72 is located at the Route 611/241 bridge crossing.

Cameron Run (listed as "Cameron Run/Hunting Creek" in the 2008 Integrated Assessment, but referred to as "Cameron Run" in this report) was listed as impaired for bacteria in Virginia's 2008 305(b)/303(d) Water Quality Assessment Integrated Report (VADEQ, 2008) due to exceedances of the state's water quality criteria for *E. coli* bacteria. The segment was first listed as impaired for *E. coli* bacteria on Virginia's 2006 Integrated List (2006 TMDL ID: 60029). The impaired segment is located within the Potomac River basin (USGS Cataloging Unit 02070010) in the City of Alexandria and Fairfax County, Virginia.

The impaired segment of non-tidal Cameron Run extends from the head of tide at approximately the Route 611/241 (Telegraph Road) bridge crossing, upstream to the confluence of Holmes Run and Backlick Run, covering approximately 2.08 miles. During the 2008 assessment period (January 2001 through December 2006), 5 out of 18 *E. coli* samples (27.8%) collected at listing station 1ACAM002.92 exceeded the *E. coli* maximum criterion of 235 cfu/100 ml. Station 1ACAM002.92 is located at the Eisenhower Avenue bridge crossing.

Holmes Run (2004 TMDL ID: VAN-A13R-02) was listed as impaired for bacteria in Virginia's 2008 305(b)/303(d) Water Quality Assessment Integrated Report (VADEQ, 2008) due to exceedances of the state's water quality criteria for *E. coli* bacteria. The segment was first listed as impaired for fecal coliform bacteria on Virginia's 2004 Integrated List. The impaired segment is located within the Potomac River basin (USGS Cataloging Unit 02070010) in the City of Alexandria and Fairfax County, Virginia.

The impaired segment of Holmes Run extends from the confluence of Holmes Run and Backlick Run upstream to the mouth of Lake Barcroft, covering approximately 3.58 miles. During the 2008 assessment period (January 2001 through December 2006), 3 out of 12 *E. coli* samples (25.0%) collected at listing station 1AHOR001.04 exceeded the *E. coli* maximum criterion of 235 cfu/100 ml. Station 1AHOR001.04 is located at the Pickett Street bridge crossing.

Table 1-1 summarizes the details of the three impaired segments.

Table 1-1: Impairment Summary for Hunting Creek, Cameron Run , and Holmes Run						
TMDL IDs	**Stream Name**	**Size**	**Boundaries**	**Station ID:**	**Impairment for**	**Exceedance Rate***
2004 ID: VAN-A13E-02 2006 ID: 00306 2008 ID: A13R-03-BAC	Hunting Creek (tidal)	0.53 square miles	Route 241 (Telegraph Road) bridge crossing to the confluence with the Potomac River	1AHUT000.01	E. coli	11 of 17 samples (40.7%)
				1AHUT001.72	E. coli	3 of 11 samples (27. 3%)
2006 ID: 60029 2008 ID: A13R-03-BAC	Cameron Run (non-tidal)	2.08 miles	Confluence with Backlick Run to the Route 241 (Telegraph Road) bridge crossing,	1ACAM002.92	E. coli	5 of 18 samples (27.8%)
2004 ID: VAN-A13R-02 2006 ID: 00795 2008 ID: A13R-02-BAC	Holmes Run (non-tidal)	3.58 miles	Mouth of Lake Barcroft to the confluence with Backlick Run	1AHOR001.04	E. coli	3 of 12 samples (25%)

* Based on the 2008 Integrated Assessment.

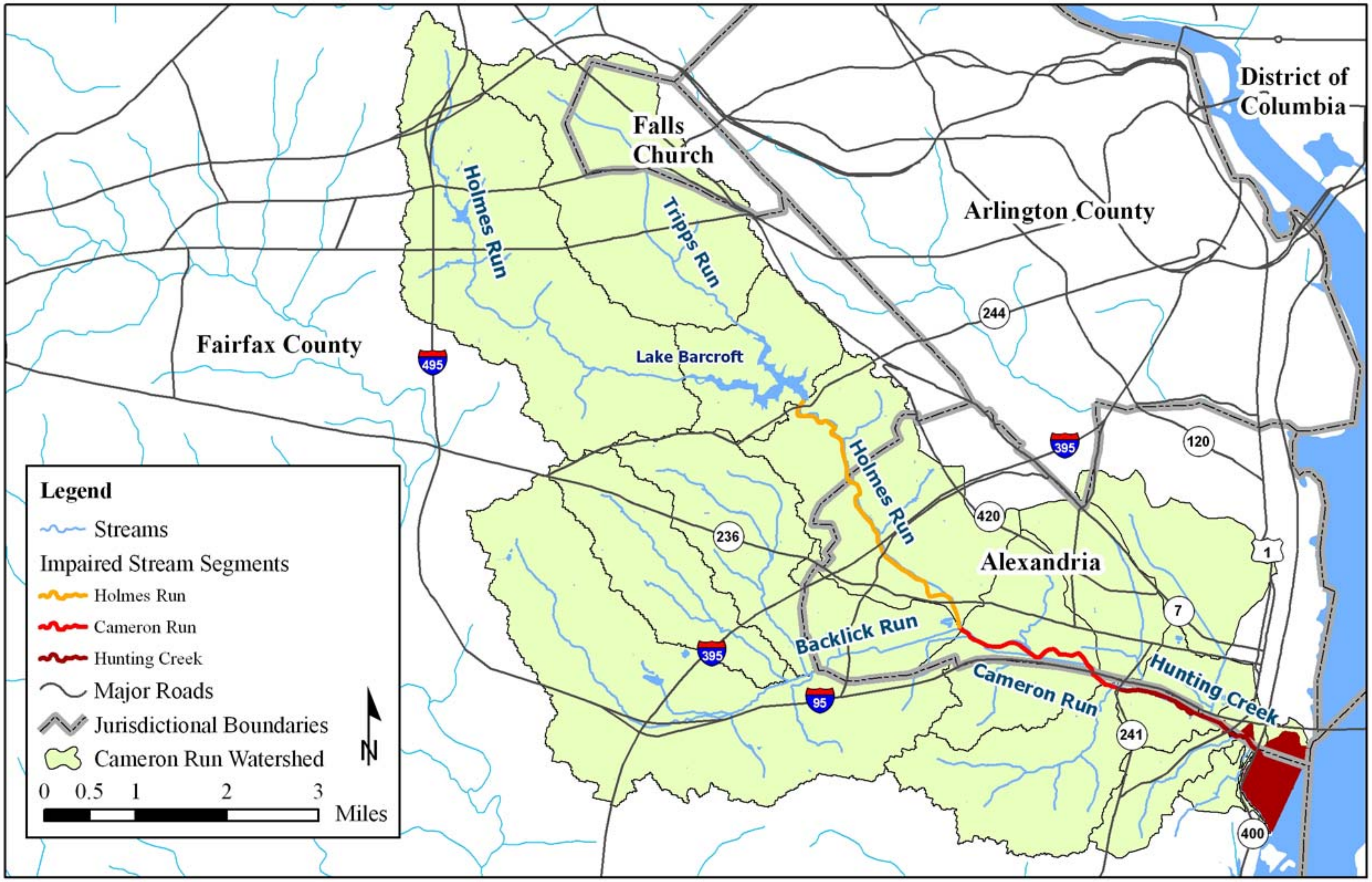


Figure 1-1: Location of the Hunting Creek, Cameron Run, and Holmes Run Watershed

1.3 Applicable Water Quality Standard

Water quality standards consist of designated uses for a waterbody and water quality criteria necessary to support those designated uses. According to Virginia Water Quality Standards (9 VAC 25-260-5), the term "water quality standards means provisions of state or federal law which consist of a designated use or uses for the waters of the Commonwealth and water quality criteria for such waters based upon such uses. Water quality standards are to protect the public health or welfare, enhance the quality of water and serve the purposes of the State Water Control Law (§62.1-44.2 et seq. of the Code of Virginia) and the federal Clean Water Act (33 USC §1251 et seq.)."

1.3.1 Designated Uses

According to Virginia Water Quality Standards (9 VAC 25-260-10):

> *"all state waters are designated for the following uses: recreational uses (e.g., swimming and boating); the propagation and growth of a balanced indigenous population of aquatic life, including game fish, which might be reasonably expected to inhabit them; wildlife; and the production of edible and marketable natural resources (e.g., fish and shellfish)."*

1.3.2 Applicable Water Quality Criteria

Effective February 1, 2010, VADEQ specified a new bacteria standard in 9 VAC 25-260-170.A. For a non-shellfish, freshwater waterbody to be in compliance with Virginia bacteria standards for primary contact recreation, the current criteria are as follows:

> *"E. coli bacteria shall not exceed a monthly geometric mean of 126 CFU/100 ml in freshwater...Geometric means shall be calculated using all data collected during any calendar month with a minimum of four weekly samples… If there are insufficient data*

> *to calculate monthly geometric means in freshwater, no more than 10% of the total samples in the assessment period shall exceed 235 E. coli CFU/100 ml."*

The previous fecal coliform criteria was phased out because research showed that there is a stronger correlation between the concentration of *E. coli* and the incidence of gastrointestinal illness than with fecal coliform. *E. coli* are bacteriological organisms that can be found in the intestinal tract of warm-blooded animals. Like fecal coliform bacteria, these organisms indicate the presence of fecal contamination.

For bacteria TMDL development after January 15, 2003, *E. coli* is the primary applicable water quality target. However, the loading rates for watershed-based modeling are available only in terms of fecal coliform. Therefore, during the transition from fecal coliform to *E. coli* criteria, DCR, DEQ and EPA have agreed to apply a translator to instream fecal coliform data to determine whether reductions applied to the fecal coliform load would result in meeting instream *E. coli* criteria. The fecal coliform model and instream translator are used to calculate *E. coli* TMDLs (VADEQ, 2003). The following regression based instream translator is used to calculate *E. coli* concentrations from fecal coliform concentrations:

$$\text{E. coli conc. (cfu/100 mL)} = 2^{-0.0172} \times [\text{fecal coliform conc. (cfu/100mL)}]^{0.91905}$$

As of the approval of the latest revisions to Virginia's Water Quality Standards (February 1, 2010), bacteria TMDLs in Virginia are only required to meet the geometric mean criteria. The modeled daily fecal coliform concentrations are converted to daily *E. coli* concentrations using the instream translator. The TMDL development process must also account for seasonal and annual variations in precipitation, flow, land use, and pollutant contributions. Such an approach ensures that TMDLs, when implemented, do not result in exceedances under a wide variety of scenarios that affect fecal coliform loading.

2 TMDL Endpoint Identification

2.1 Selection of TMDL Endpoint and Water Quality Targets

One of the first steps in TMDL development is determining the numeric endpoints, or water quality targets, for each impaired segment. Water quality targets compare the current stream conditions to the expected restored stream conditions after TMDL load reductions are implemented. Numeric endpoints for the Holmes Run, Cameron Run, and Hunting Creek TMDLs are established in the Virginia Water Quality Standards (9 VAC 25-260). These standards state that all waters in Virginia should be free from any substances that can cause the water to exceed the state numeric standards, interfere with its designated uses, or adversely affect human health and aquatic life. Therefore, the current water quality target for this impairment, as stated in 9 VAC 25-260-170, is an *E. coli* geometric mean no greater than 126 colony-forming units (cfu) per 100 ml for four or more weekly water quality samples taken during any calendar month.

Critical Condition

The critical condition is considered the "worst case scenario" of environmental conditions in the Cameron Run/Hunting Creek watershed. If TMDLs are developed such that all water quality targets are met under the critical condition, then these targets would also be met under all other conditions.

EPA regulations, 40 CFR 130.7 (c)(1), require TMDLs to take critical conditions for stream flow, loading, and water quality parameters into account. The intent of this requirement is to ensure that the water quality of Holmes Run, Cameron Run, and Hunting Creek are protected during times when they most vulnerable. Critical conditions are important because they describe the combination of factors responsible for exceedances of water quality criteria. They will help in identifying the actions that may have to be undertaken in order to meet water quality standards.

The Hunting Creek/Cameron Run watershed is mostly developed. No land is used for agriculture in the watershed. Residential land uses make up over 50% of the watershed's land area. Only 12% of the land is comprised of parks, golf courses, or open space. The key potential sources of bacteria are related to a heavy urban land use: pets, wildlife, sanitary sewer overflows (SSOs) and cross-connections between sanitary and storm sewer systems. In the tidal waters of Cameron Run and Hunting Creek, the Alexandria Sanitation Authority's Advanced Wastewater Treatment Plant (ASA WWTP) has a Virginia Pollutant Discharge Elimination System (VPDES) permit which authorizes the discharge of bacteria. The permit requires the WWTP to meet the geometric mean water quality criterion at the point of discharge. The City of Alexandria also has a combined sewer system (CSS) which discharges into tidal Hooff Run and Hunting Creek**.**

Figures 2-1 through **2-5** show the concentrations of fecal coliform, *E. coli*, and the translated *E. coli* values (resulting from using the translator as explained in Chapter 1 to convert fecal coliform data to *E. coli* data), all in cfu/100 ml, that were observed at stations 1ACAM002.92, 1AHOR001.04, 1AHOR001.78, 1AHUT000.01, and 1AHUT001.72. The maximum criterion (400 cfu/100 ml for fecal coliform and 235 cfu/100 ml for *E. coli*) is represented in each figure by a red line.

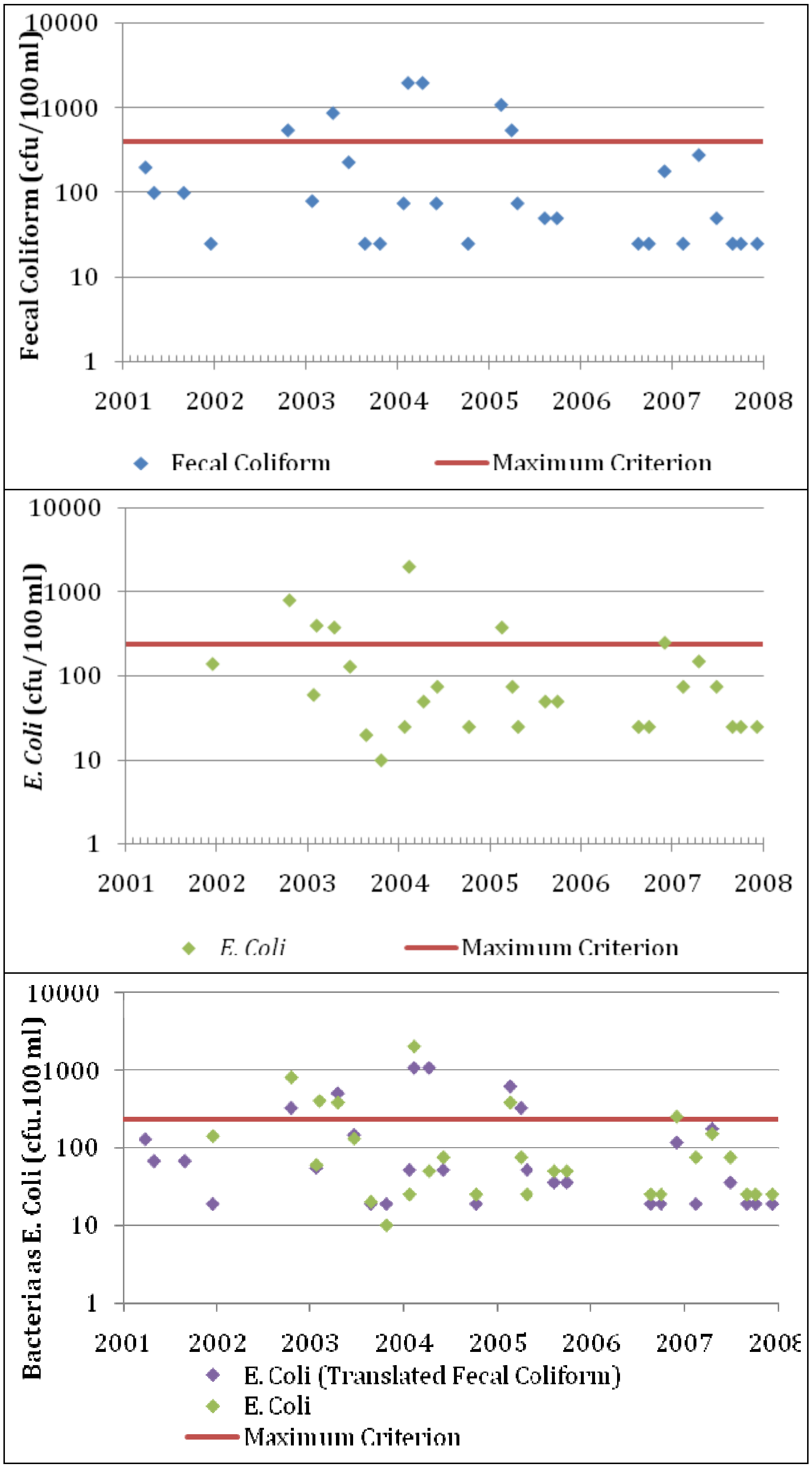


Figure 2-1: Cameron Run bacteria concentrations at station 1ACAM002.92

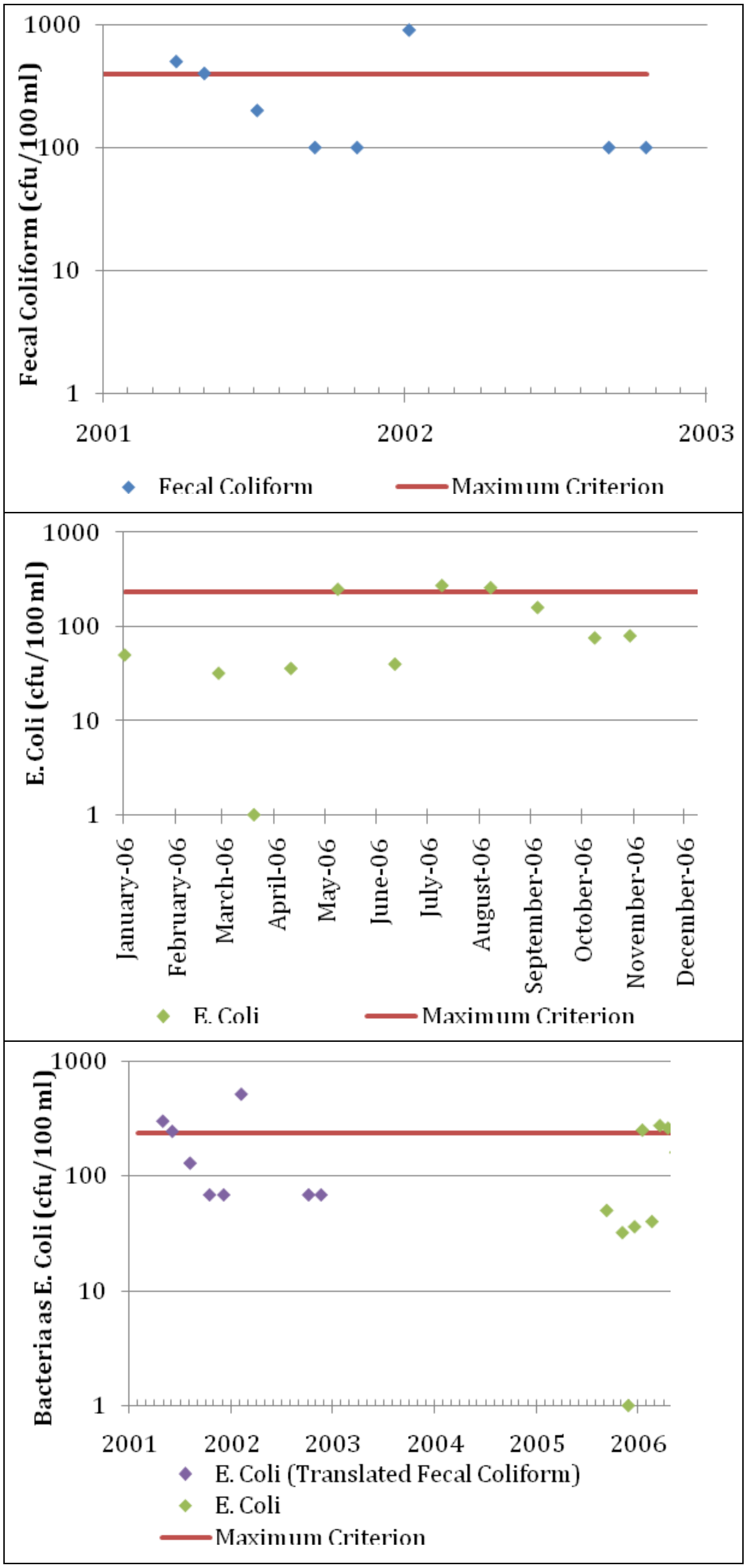


Figure 2-2: Holmes Run bacteria concentrations at station 1AHOR001.04

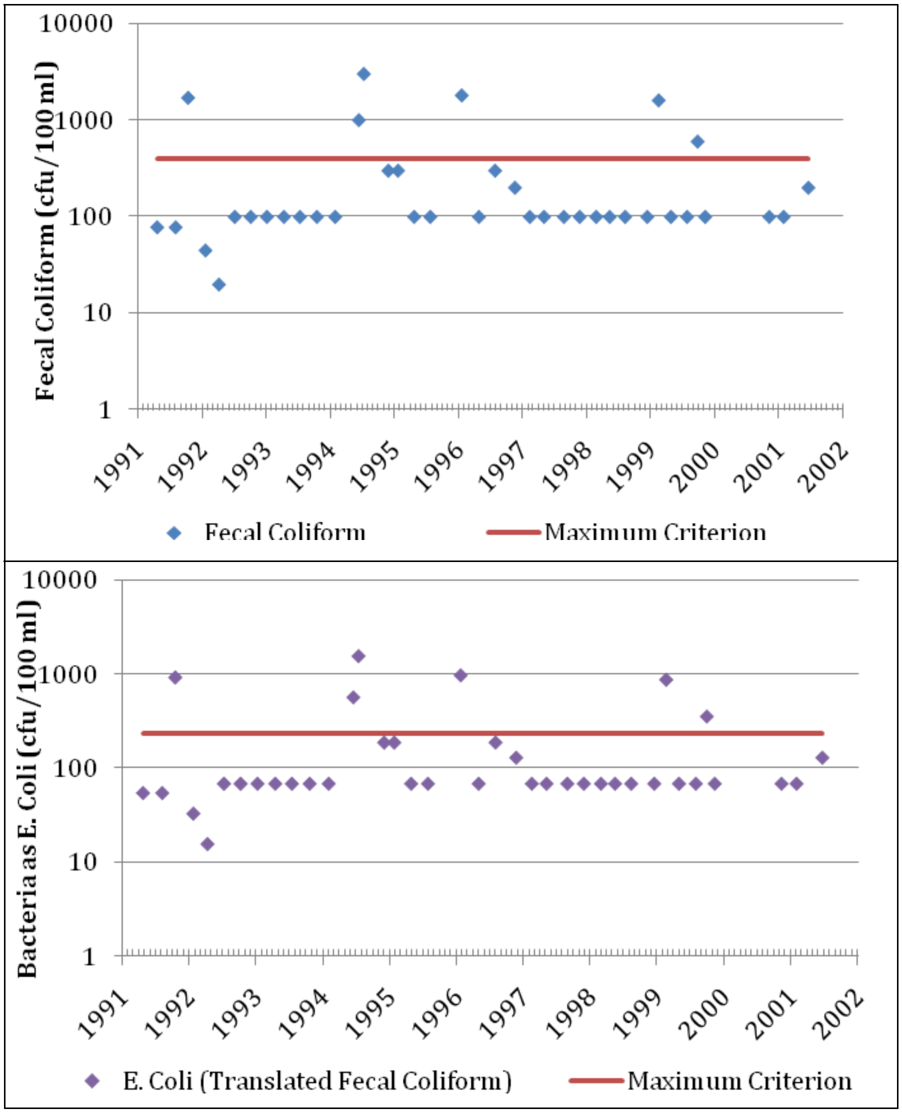


Figure 2-3: Holmes Run bacteria concentrations at station 1AHOR001.78

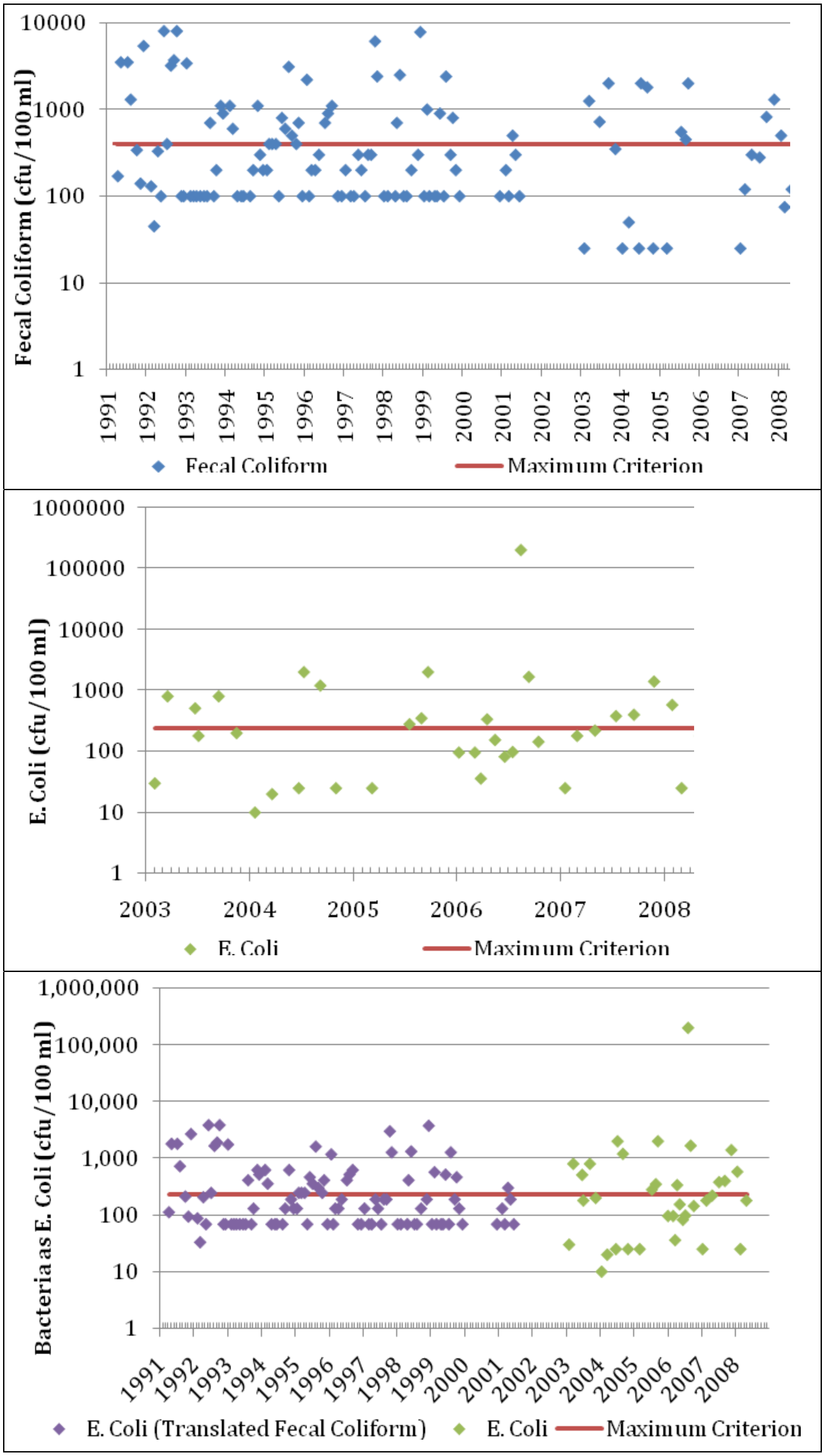


Figure 2-4: Hunting Creek bacteria concentrations at station 1AHUT000.01

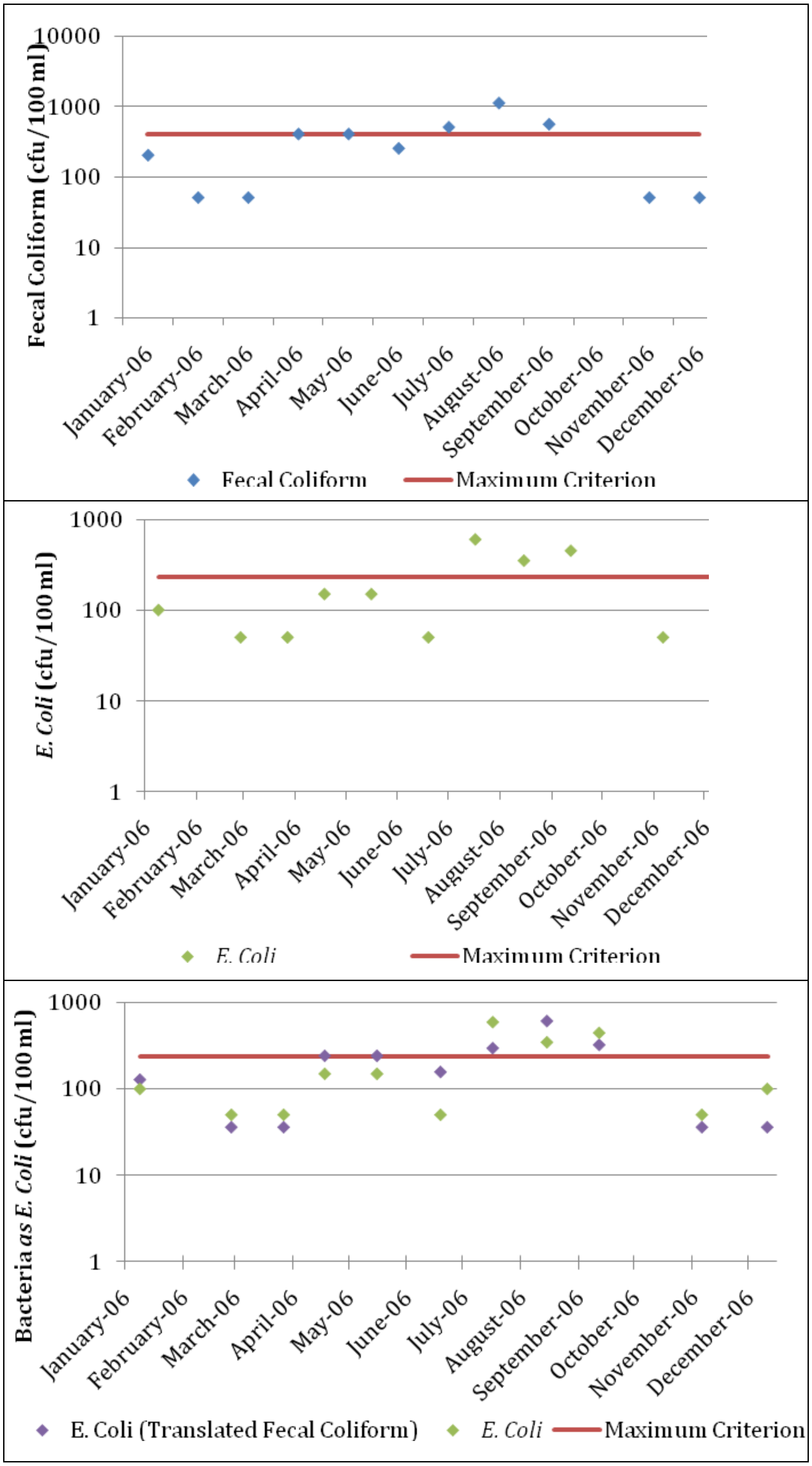


Figure 2-5: Hunting Creek bacteria concentrations at station 1AHUT001.72

The above figures indicate that the maximum criteria for both fecal coliform and *E. coli* were exceeded at all monitoring stations over the sampling period, which varies by station.

It is necessary for the critical condition to consider both wet weather, high flow conditions and dry weather, low flow conditions in order to comply with the geometric mean bacteria standard.

2.3 Consideration of Seasonal Variations

Seasonal variations involve changes in stream flow and water quality because of hydrologic and climatological patterns. Seasonal variations were explicitly included in the modeling approach for this TMDL. The continuous simulation model developed for this TMDL explicitly incorporates the seasonal variations of rainfall, runoff, and fecal coliform wash-off by using an hourly time-step. Seasonal variations in the tidal cycle were also explicitly simulated in the representation of tidal waters. These measures allowed the consideration of temporal variability in fecal coliform loading within the watershed.

3 Watershed Description and Source Assessment

In this section, the types of data available and information collected for the development of the TMDLs for Holmes Run, Cameron Run, and Hunting Creek are presented. This information was used to characterize the segment and its watershed and to inventory and characterize the potential point and non-point sources of fecal coliform in the watershed.

3.1 Data and Information Inventory

A wide range of data and information were used in the development of these TMDLs. Categories of data that were used include the following:

- Physiographic data that describe physical conditions (i.e., topography, soils, and land use) within the watershed.
- Data that describe physical conditions within the tidal river and embayment, such as channel depth, width, slope, and elevation.
- Data related to land uses of the watershed, wildlife and pet populations, and information that can be used in the identification of potential fecal coliform sources.
- Environmental monitoring data that describe stream flow, tidal elevations, and water quality conditions in the watershed and tidal embayment.

Table 3-1 shows the various data types and the data sources used in the TMDL development for the Holmes Run, Cameron Run, and Hunting Creek watershed.

Table 3-1: Inventory of Data and Information Used in the Holmes Run, Cameron Run, and Hunting Creek Bacteria TMDL

Data Category	Description	Source(s)
Watershed physiographic data	Watershed boundary	NHD, VADEQ
	Land use/land cover	Fairfax, Fall Church, Alexandria, USACE
	Soil data (SSURGO, STATSGO)	NRCS
	Bathymetry data	VDOT, USACE
	Topographic data (USGS-30 meter DEM, USGS Quads)	USGS, DCR
Hydrographic data	Stream network and reaches (RF3)	NHD
	Stream morphology	
Weather data	Hourly meteorological conditions	CBPO, NOAA
Watershed activities/ uses data and information related to fecal coliform production	Information, data, reports, and maps that can be used to support fecal coliform source identification and loading	Fairfax, Falls Church, Alexandria, local groups and stakeholders
	Wildlife inventory	DGIF, NVRC, Fairfax, Alexandria
	Septic systems inventory and failure rates	Fairfax, U.S. Census Bureau
	Best management practices (BMPs)	DCR, NRCS, local SWCDs
Regulated sources and direct discharge data and information	Permitted facilities locations and discharge monitoring reports (DMRs)	VPDES, VADEQ
	Combined sewer overflows	Alexandria
	Sanitary sewer overflows	VADEQ
Environmental monitoring data	Water quality monitoring data	VADEQ, Alexandria
	Tidal elevation data	NOAA, USGS
	Stream flow data	USGS, VADEQ

Notes:
BMPs: Best Management Practices
CBPO: Chesapeake Bay Program Office
DCR: Virginia Department of Conservation and Recreation
DEM: Digital Elevation Model
DMRs: Discharge Monitoring Reports
DGIF: Virginia Department of Game and Inland Fisheries
EPA: Environmental Protection Agency
NCDC: National Climatic Data Center
NHD: National Hydrography Dataset
NOAA: National Oceanic and Atmospheric Administration
NRCS: Natural Resources Conservation Service
NVRC: Northern Virginia Regional Commission
SSURGO: Soil Survey Geographic Database
STATSGO: State Soil Geographic Database
SWCD: Soil and Water Conservation District
USGS: U.S. Geological Survey
USACE: U. S. Army Corps of Engineers
VADEQ: Virginia Department of Environmental Quality
VDOT: Virginia Department of Transportation
VPDES: Virginia Pollutant Discharge Elimination System

3.2 Watershed Description and Identification

The impaired segments of Holmes Run, Cameron Run, and Hunting Creek are shown in Figure 3-1. As Figure 3-1 shows, the impaired section of Holmes Run is part of the drainage to the impaired section of Cameron Run, which in turn is part of the drainage to tidal Hunting Creek. Unless specified, the entire watershed, including the drainage upstream of the impaired portion of Holmes Run, will be referred to as "the Cameron Run watershed" or "the Hunting Creek drainage." The impaired segments are located in the Potomac River basin (USGS segment 02070010). The impaired segments begin at the outlet of Lake Barcroft and extend to the confluence of the Potomac River.

As Figure 3-1 shows, a large portion of the Cameron Run watershed is in Fairfax County, with a very small portion is in Arlington County. The watershed also occupies a large portion of the independent cities of Falls Church and Alexandria, in Northern Virginia. The entire watershed is highly developed. There are no agricultural activities in the watershed; approximately 90% of the watershed has been built-out. Hunting Creek flows into the Potomac River at the City of Alexandria, a colonial seaport associated with George Washington and Robert E. Lee. The headwaters of Holmes Run are in Tyson's Corner, which is famous for its high concentration of retail businesses and high-technology companies.

As shown in **Figure 3-1**, the major roadways that run through the watershed include Interstate 95, running from east to west through the southern portion of the watershed; Interstate 495, running from north to south along the western portion; Interstate 395 running northeast to southwest through the center of the watershed; and a small portion of Interstate 66, running from east to west along the northern portion of the watershed. Interstate 95 and 495 together make up Virginia's portion of the Capital Beltway. Other major roads include state highways 241, 338, 400, and 402 running from north to south; state highways 29, 50, 236, 244, and 401 running from east to west; state highways 7 and 420 running from northwest to southeast; and State Highway 401 running from northeast to southwest.

Lake Barcroft is located in the upper portion of the watershed and is fed by two streams: Holmes Run and Tripps Run. Holmes Run flows out of Lake Barcroft and downstream to join with Backlick Run to form Cameron Run. Lake Barcroft is a former water supply reservoir for the City of Alexandria (COA), built in 1915. COA outgrew the reservoir in the

1940's. Today, the 135 acre reservoir is owned by the Lake Barcroft Association on behalf of the residents. The dam is operated by the Lake Barcroft Watershed Improvement District, (WID), a Virginia state agency. The WID is also responsible for environmental and water quality management of the lake.

Several other features of the Cameron Run watershed deserve special mention. First, Cameron Run is prone to flooding. Most recently, in June of 2006, flood waters covered portions of the Capital Beltway, along with several other major roadways in the watershed, and caused an estimated $10,000,000 of damage in the Huntington area of Fairfax County (USACE, 2007). The U.S. Army Corps of Engineers (USACE) is working together with the Federal Emergency Management Agency (FEMA), The Northern Virginia Regional Commission (NVRC), Fairfax County and the City of Alexandria on a flood control study of Cameron Run.

A major construction project that has impacted the watershed is the reconstruction of the Woodrow Wilson Bridge. The original bridge, completed in 1961, was replaced in 2008 by twin spans which essentially doubled the capacity of the original bridge. Construction impacted not only the new bridges' Virginia termini in Hunting Creek but also sections and interchanges on Interstate 95/495 along the Cameron Run waterfront.

Finally, like many older cities in the United States, Alexandria has a combined sewer system (CSS) of approximately 560 acres, primarily in the "Old Town" section of Alexandria. Alexandria's CSS will be described in greater detail in Chapter 5. Alexandria's CSS is one of three CSS still in operation in the Commonwealth of Virginia. The other two systems are located in the cities of Richmond and Lynchburg.

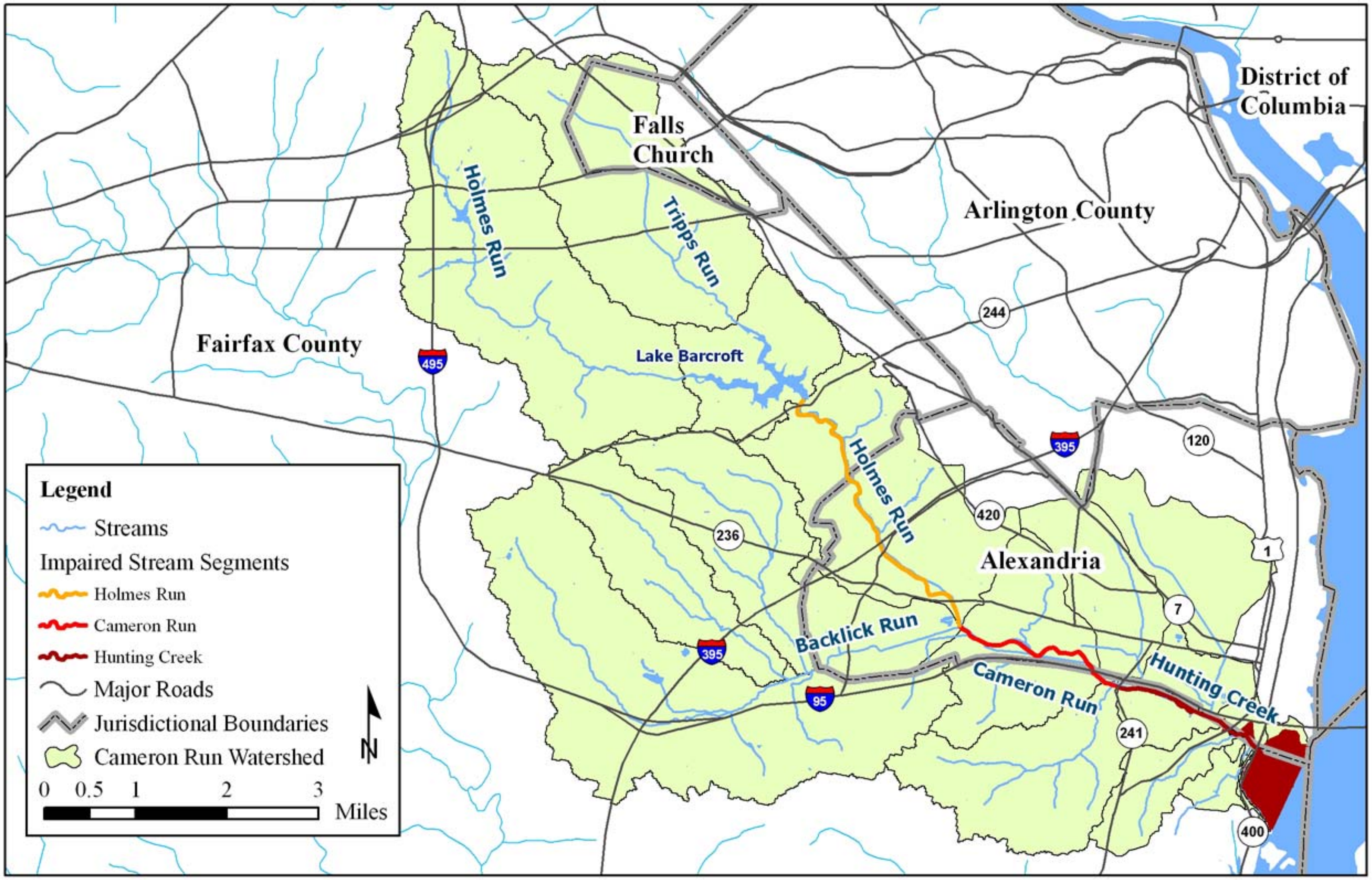


Figure 3-1: Location and Boundary of the Holmes Run, Cameron Run, and Hunting Creek Watershed

3.21 Topography

A digital elevation model (DEM) was used to characterize the topography in the watershed. DEM data obtained from USGS show that elevation in the watershed ranges from approximately 1 to 150 feet above mean sea level, with an average elevation of 70 feet above mean sea level.

3.2.2 Soils

The Holmes Run, Cameron Run, and Hunting Creek watershed soil characterization was based on data obtained from the U.S General Soil Map (STATSGO). There are four general soil associations located in the watershed (**Table 3-2)**. Quantico-Neabsco-Dumfries soils cover 34% of the watershed, Occoquan-Meadowville-Buckhall soils cover 33%, and Suffolk-Rumford-Emporia soils cover 29%, with Manor-Glenelg soils occupying only 1% of the watershed.

Table 3-2: Major Soil Associations within the Holmes Run, Cameron Run, and Hunting Creek Watershed

Soil Name	Acres	Percentage of the Watershed
Manor-Glenelg (s3166)	361	1%
Occoquan-Meadowville-Buckhall (s8273)	9,991	33%
Quantico-Neabsco-Dumfries (s8285)	10,156	34%
Suffolk-Rumford-Emporia (s8287)	8,739	29%
Water (s8369)	726	3%
Total	**29,973**	**100%**

The hydrologic soil group linked with each soil association is presented in **Table 3-3**. The hydrologic soil groups represent different levels of infiltration capacity of the soils. Hydrologic soil group "A" designates soils that are well to excessively well drained, whereas hydrologic soil group "D" designates soils that are poorly drained. Consequently, more rainfall becomes part of the surface water runoff along poorly drained soils. Descriptions of the hydrologic soil groups are presented in **Table 3-4**. On the scale of STATSGO, as Table 3-3 shows, the soils in the Cameron Run watershed are predominately moderately well drained soils of hydrologic soil group B.

Table 3-3: Soil Hydrologic Groups within the Holmes Run, Cameron Run, and Hunting Creek Watershed		
Soil Hydrologic Group	**Acres**	**Percentage of Watershed**
B	29,247	97%
Water	726	3%
Total	**29,973**	**100%**

Table 3-4: Descriptions of Soil Hydrologic Groups	
Soil Hydrologic Group	**Description**
A	High infiltration rates. Soils are deep, well-drained to excessively-drained sand and gravels.
B	Moderate infiltration rates. Deep and moderately deep, moderately well and well-drained soils with moderately coarse textures.
C	Moderate to slow infiltration rates. Soils with layers impeding downward movement of water or soils with moderately fine or fine textures.
D	Very slow infiltration rates. Soils are clayey, have a high water table, or shallow to impervious cover.

3.2.3 Land Use

The land use characterization for the Holmes Run, Cameron Run, and Hunting Creek watershed was based on zoning and land cover data provided by Fairfax County, VA (Bennett, 2009); City of Alexandria, VA (Kanzler, 2009); and City of Falls Church, VA (Kahn, 2009). Zoning data from the US Army Corps of Engineers (Thomas, 2009) was used for the small portion (0.1 %) of the watershed located in Arlington County, VA. Fairfax County provided separate geographic information systems (GIS) layers for the Cameron Run watershed and the area downstream of Telegraph Road, which, according to Fairfax County's watershed delineations, is part of the Belle Haven watershed.

The jurisdictions' own land use categories were converted to a common set of land use classifications according to Table 3-5. Six major land use categories were used: water, residential, industrial, commercial, transportation, and open space. These were subdivided into 14 minor categories shown in Table 3-5. Table 3-6 describes these categories.

Figure 3-2 depicts the land use distribution in the watershed. **Table 3-7** shows the classification of land uses in the Holmes Run watershed. **Table 3-8** shows the classification of land uses in the non-tidal Cameron Run watershed (including Holmes Run). **Table 3-9** shows the land uses in the entire Cameron Run/ Hunting Creek drainage. The difference in acreage between Table 3-9 and Table 3-2 is due to differences in the estimate of the number of water acres. Overall, the watershed is about 87% developed with residential areas accounting for 53%, followed by transportation (16%), commercial use (15%), and industrial use (3%). Approximately 12% of the watershed is open space.

Table 3-5: Classification of Jurisdiction land Use Categories

Zoning Codes		Source / Shapefile (Field)				
Land Use Category	Zoning Category	ACE	Alexandria	Falls Church	Belle Haven	Fairfax County
		zoning_ar (HMS_LU)	Zoning_y (Zoning)	zoning ZN_CODE	BelleHaven_Landuse_120808 (LU_exist)	ca-base_year_scenario_land_use_(CLU_CODE)
Water	Water	OPEN WATER			WATER	OW
Open Space	Forest	FOREST				
	Open space	OPEN SPACE	POS, WPR		GC, OS	OS
	Vacant/ underutilized					VUR
Residential	High-density	HEAVY RESIDENTIAL	CRMU/X, R2-5, RB, RC, RCX, RM, RT	R-C, R-M, R-TH	HDR	HDR
	Medium-density	MEDIUM RESIDENTIAL	R5, R8, R12, RA	R-1B	MDR	MDR
	Low-density	LIGHT RESIDENTIAL	R20, RD	R-1A	ESR, LDR	ESR, LDR
Commercial	Mixed use		CRMU/H, CRMU/L, CRMU/M, W-1			
	Transitional/ development		CDD #1, CDD #2, CDD #3, CDD #4, CDD #8, CDD #9, CDD #10, CDD #11, CDD #14	C-D, O-D, T-1, T-2		
	Commercial	COMMERCIAL	CC, CD, CDX, CG, CL, CR, CSL, KR, OC, OCH, OCM(100), OCM(50)	B-1, B-2, B-3		
	High-intensity commercial				HIC	HIC
	Low-intensity commercial				INT, LIC	LIC
Industrial	Industrial	INDUSTRIAL	I	M-1	IND	IND
Transportation	Transportation/ Utilities	IMPERVIOUS	UT		TRANS	TRA

Table 3-6: Zoning and Land Cover Categories within the Holmes Run, Cameron Run, and Hunting Creek Watershed

Model Land Use	Zoning	Description
Open Space	Forest	Areas dominated by trees.
	Open Space	Public open spaces, parks, recreation zones, and golf courses are included in this category.
	Vacant /underutilized	In these parcels the existing land use is significantly less than zoned or planned, or the parcels are vacant.
Residential	Low density	This category includes estate residential areas, single family homes on 8,000 square foot or larger lots, and townhouse developments with nine or fewer units per acre.
	Medium density	Single and two family homes, townhouses, and medium density apartment dwellings are permitted in these neighborhoods.
	High density	These areas area zoned for high rise, high density multifamily structures and cluster residences.
Commercial	Mixed use	A mix of residential and commercial uses a permitted in these zones.
	Transitional/ development	This category includes transitional areas and coordinated development districts.
	Low intensity commercial	These areas are zoned for low intensity commercial uses.
	Commercial	These are developed areas in which commercial uses predominate.
Industrial	Industrial	These parcels are zoned for industrial uses.
Transportation	Transportation/ Utilities	These areas include utilities and infrastructure (e.g., roads, railroads).

Table 3-7: Land Use in Holmes Run Watershed					
Land Use Category	**Zoning Category**	**Acres**		**Percent of Watershed**	
Water	Water	142	142	1.2%	1.2%
Open Space	Forest	0	1,291	< 1%	10.6%
	Open space	737		6.0%	
	Vacant/underutilized	553		4.5%	
Residential	High-density	727	7,008	5.9%	57.3%
	Medium-density	4,549		37.2%	
	Low-density	1,732		14.2%	
Commercial	High-intensity commercial	135	1,728	1.1%	14.1%
	Low-intensity commercial	948		7.7%	
	Commercial	231		1.9%	
	Mixed use	27		< 1%	
	Transitional/development	387		3.2%	
Industrial	Industrial	63	63	< 1%	0.5%
Transportation	Transportation/Utilities	2,003	2,003	16.4%	16.4%
Total		**12,235**		**100%**	

Table 3-8: Land Use in Cameron Run Watershed*					
Land Use Category	**Zoning Category**	**Acres**		**Percent of Watershed**	
Water	Water	142	142	< 1%	0.6%
Open Space	Forest	0	3,156	< 1%	12.6%
	Open space	1,702		6.8%	
	Vacant/underutilized	1,454		5.8%	
Residential	High-density	1,578	13,166	6.3%	52.7%
	Medium-density	7,827		31.3%	
	Low-density	3,761		15.0%	
Commercial	High-intensity commercial	399	3,430	1.6%	13.7%
	Low-intensity commercial	1,842		7.4%	
	Commercial	582		2.3%	
	Mixed use	45		< 1%	
	Transitional/development	561		2.2%	
Industrial	Industrial	903	903	3.6%	3.6%
Transportation	Transportation/Utilities	4,211	4,211	16.8%	16.8%
Total		**25,007**		**100%**	

**** Includes land use for Holmes Run Watershed.***

Table 3-9: Land Use within the Cameron Run /Hunting Creek Drainage

Land Use Category	Zoning Category	Acres		Percent of Watershed	
Water		163	163	< 1%	1%
Open Space	Forest	1	3,590	< 1%	12%
	Open Space	2,108		7 %	
	Vacant /underutilized	1,481		5 %	
Residential	Low density	4,166	15,598	14 %	53%
	Medium density	9,115		31 %	
	High density	2,317		8 %	
Commercial	Mixed use	83	4,055	< 1 %	15%
	Transitional/development	797		3 %	
	Low intensity commercial	1,899		7 %	
	Commercial	1,276		4 %	
Industrial	Industrial	981	981	3%	3%
Transportation	Transportation/Utilities	4,791	479	16%	16%
Total		**29,179[1]**		**100%**	

[1] *Includes both Holmes Run and Cameron Run watersheds.*

An estimation of the impervious area within each watershed was based on polygon and line GIS layers representing building footprints and paved areas (e.g., roads, parking lots, driveways, and sidewalks). The layers were provided by Fairfax County (Bennett, 2009), and the cities of Alexandria (Kanzler, 2009), and Falls Church (Kahn, 2009). Using standard GIS tools and procedures, the various layers were combined to obtain a representation of the impervious area in each subwatershed, which then was apportioned by land use. Table 3-10 shows the shapefiles provided by the jurisdictions to estimate impervious area. Details of the treatment of specific features are described below.

<u>Roads and Parking Lots</u> – These polygon layers show areas covered by transportation features (e.g., roads, shoulders, medians, bridges) and parking lots, and were classified as either paved or unpaved. Paved areas were deemed to be 100% impervious and unpaved areas as 50% impervious. When a classification was not provided for a polygon, it was considered to be 75% impervious.

<u>Sidewalks</u> – The City of Alexandria provided sidewalks as a polygon shapefile. Fairfax County provided a line features, which either represented the centerline or both edges of the sidewalks. In the former case the sidewalk length was multiplied by an average sidewalk width of four feet and in the latter case by half the sidewalk width so that the areal extent of the sidewalks could be estimated. The City of Falls Church did not provide a sidewalk shapefile, but rather a shapefile of road edges. Again, the length of the road edges was multiplied by four feet. Sidewalks were assumed to be 85% impervious.

<u>Buildings</u> - The buildings polygon layer contained building footprints and a description of the building types (**Table 3-11**). Buildings were presumed to be 100% impervious. When the building type was not provided, the buildings were classified according to zones in which they were located (**Table 3-12**). When building polygons overlapped road, parking lot, or sidewalk polygons, standard GIS procedures were used to subtract the overlap area in order to avoid double counting impervious area.

Not all impervious areas drain into storm sewers. For example, drainage from roofs of detached low density single family residences is often directed onto lawns rather than onto driveways or other structures hydraulically connected to storm sewers. Therefore, a faction of roof drainage from low density zones was separate from the directly connected impervious area (DCIA) and classified as pervious area. DCIA fractions were taken from a memorandum prepared by Camp. Dresser, and McGee (2003) for Fairfax County on the use of GIS information in stormwater models. **Table 3-13** shows the fraction of buildings and other features considered DCIA.

<u>Driveways</u> – Only the City of Alexandria provided a driveway polygon layer. In the remainder of the watershed, the areal extent of driveways was presumed to cover 1,000 square feet per single family residential building. All driveways were assumed to be 100% impervious.

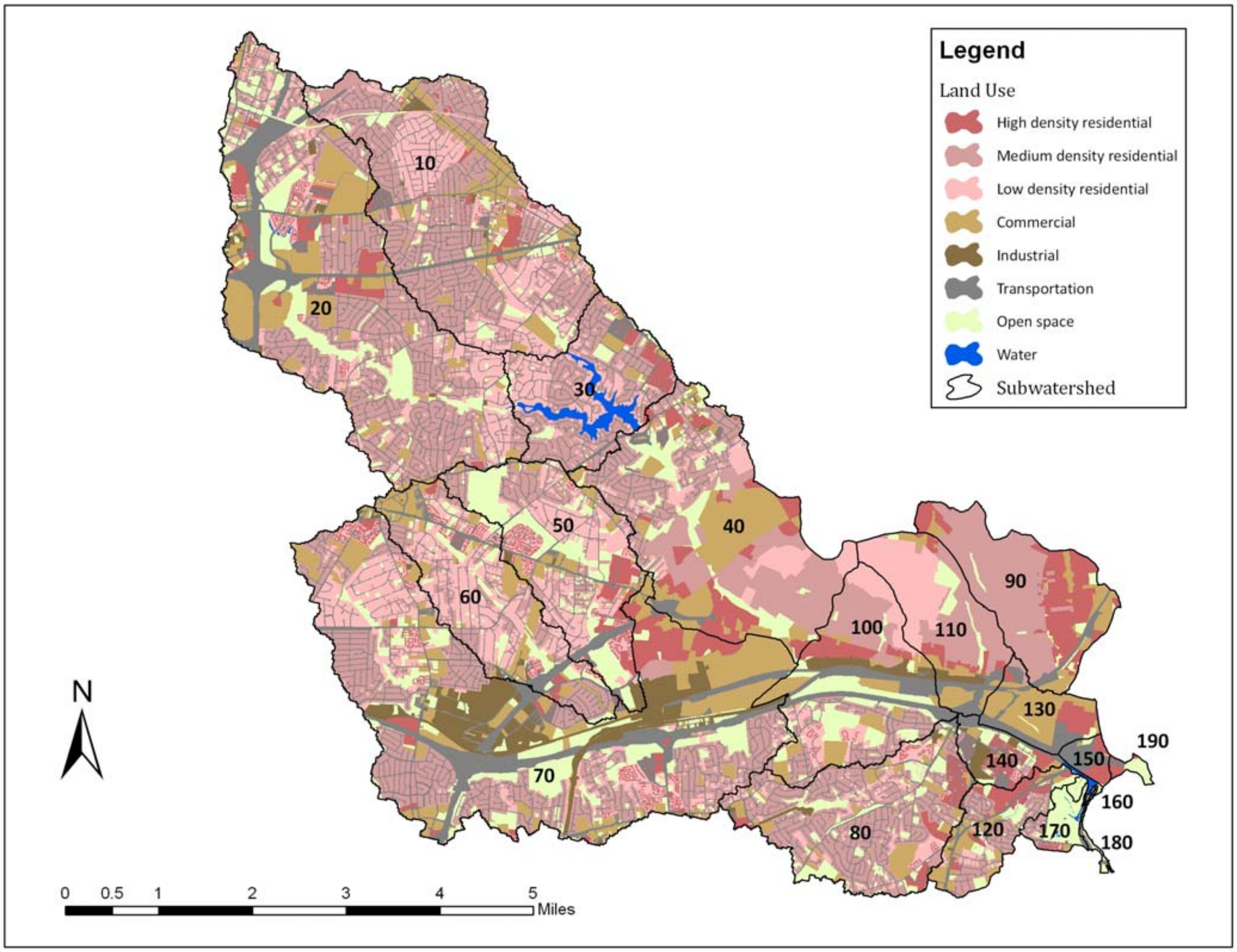


Figure 3-2: Land Use in the Holmes Run, Cameron Run, and Hunting Creek Watershed

Table 3-10: Shapefiles used to Estimate Impervious Area

Feature	Jurisdiction			
	Alexandria	**Falls Church**	**Bellhaven**	**Fairfax County**
Building Footprints	Bld_y (p)	building (p)	BuildingOutlines(p)	BuildingOutlines(p)
Roads	Road_y (p)	roads poly (p)	EoPMajor	EoPMajor
Parking lots	Parklot_y (p)	parking	EoPMinor	EoPMinor
Driveways	Driveway_y (p)	**Estimated based on single family residences**		
Sidewalks	Walk_y (p)	Estimated from road edges(l)	sidewalks (l)	sidewalks (l)

Table 3-11: Classification of Building Types

Building Type	Codes	Notes
Single family residential	SFR	
Multifamily residential	A, CM, TH, MFR	Includes apartment, condominium, townhouse, multifamily residential
Public	P	e.g., schools, libraries, community centers, government centers, parking garages, hospitals
Other	M, O, R/C	Metro station, other, religious/charitable
Non enclosed	NON	Court yards and other internal spaces surrounded by a building
Commercial	C	
Industrial	I	
Not classified	NC	These were reclassified based on the zoning

Table 3-12: Reclassification of Building Types

If in zone…	Building classified as …
COM	C
Industrial	I
HDR	MFR
LDR, MDR	SFR
OSP	Public

Table 3-13: Directly Connected Impervious Area (DCIA) by Land Use

Impervious Feature	Type	Fraction DCIA
Sidewalk	N/A	0.85
Buildings	Commercial	1
	Industrial	0.95
	Multifamily residential	0.9
	Other	0.85
	Public	0.85
	Single family residential	0.5
Transportation Features: Roads, shoulders, medians, parking lots, driveways	Paved	1
	Unpaved	0.5
	Not classified	0.75

3.2.4 Tidal Cameron Run /Hunting Creek Bathymetry

Detailed bathymetric data were available in the tidal Hunting Creek from two special projects. First, the USACE (2007) developed a HEC-RAS (River Analysis System) model of the portion of Cameron Run/Hunting Creek above the George Washington Memorial Parkway as part of a flood control design study for the Federal Emergency Management Agency (FEMA) in response to the June 2006 flood event. As part of model development, USACE obtained river cross sections used in the development of previous Virginia Department of Transportation (VDOT) HEC-RAS model. The cross-sections were based on field surveys performed 1999-2001. USACE (Thomas, 2008) generously made these files available for model development for the Hunting Creek/Cameron Run Bacteria TMDL.

The Woodrow Wilson Bridge Project was a source of bathymetric data in Hunting Creek on the Potomac side of George Washington Memorial Parkway. In conjunction with the construction of the new bridge, VDOT conducted new bathymetric field surveys of selected sites in Hunting Creek (Finerfrock, 2009). This data was also incorporated into the Hunting Creek/Cameron Run TMDL model development.

3.3 Stream Flow Data and Tidal Elevations

3.3.1 Stream Flow Data

Stream flow data were available at one USGS stream flow-gauging stations located within the Holmes Run, Cameron Run, and Hunting Creek watershed. This station is located on Cameron Run below the confluence of Holmes Run and Backlick Run (**Figure 3-4**). The period of record at this station is shown in **Table 3-14.** The average mean daily flow over the period of record is 38.1 cubic feet per second (cfs). Ten percent of mean daily flows exceed 75 cfs, while 90% of mean daily flows exceed 4.9 cfs.

Table 4-14: USGS Stream Flow Data located in Cameron Run

Station ID	Station Name	Period of Daily-Mean Data	
		Start Date	End Date
01653000	Cameron Run at Alexandria, VA	June 1955	Present

3.3.2 Tidal Elevations

The National Oceanic and Atmospheric Administration (NOAA) maintains a long-term tidal station at Washington, DC (8594900) in the Ship Channel. The period of record for the station is 1924 to the present. The mean lower low water (MLLW) datum is -1.39 feet and the mean higher high water (MHHW) datum is 1.78 feet, relative to the North American Vertical Datum of 1988 (NAVD88), for a diurnal tidal range of 3.17 feet.

The USGS installed a tidal elevation gage (0165258890) on the Potomac River at the Cameron Street Docks in Alexandria in July, 2004. The station is located 0.8 miles upstream from the Woodrow Wilson Bridge. The maximum and minimum recorded elevations for the period July 2004 through September 2007 are 5.54 feet and -3.55 feet, respectively, relative to the NAVD88 datum. The station has not been in operation long enough to determine meaningful MLLW and MHHW.

Summary information on the tidal elevation stations is presented in **Table 3-15**.

Table 3-15: Tidal Elevation Data Located near the Hunting Creek/Cameron Run Watershed

Station ID	Agency	Station Name	Period of Data	
			Start Date	End Date
8594900	NOAA	Washington, DC	1924	Present
0165258890	USGS	Potomac River at Cameron Street Docks, Alexandria VA	July 2004	Present

3.4 Ambient Water Quality Data

3.4.1 VADEQ Monitoring Stations

VADEQ has monitored ambient water quality at six locations in the Holmes Run, Cameron Run, and Hunting Creek watershed in various periods between 1991 and 2008. A list of those monitoring stations is provided in **Table 3-16** and the locations of these stations are presented in **Figure 3-3**. Station identification numbers include the abbreviated creek name, and the river mile on that creek where the station is located. The river mile number represents the distance from the mouth of the creek.

Table 3-16: VADEQ Holmes Run, Cameron Run, and Hunting Creek Water Quality Monitoring Stations

Station ID	Station Description	Stream Name	Monitoring Period
1AHUT000.01	George Washington Memorial Pkwy	Hunting Creek (Tidal)	4/1991 – 5/2008
1AHUT001.72	Telegraph Road	Hunting Creek (Tidal)	1/2006 – 12/2006
1ACAM002.92	Eisenhower Avenue	Cameron Run (Non-Tidal)	8/2001 – 5/2008
1AHOR001.04	Pickett Street (off Holmes Run Pkwy @ Park)	Holmes Run (Non-Tidal)	8/2001 – 11/2006
1AHOR001.78	Beauregard Street	Holmes Run (Non-Tidal)	4/1991 – 6/2001
1ABAL001.40	Rt. #401 Van Dorn Street	Backlick Run (Non-Tidal)	4/1991 – 11/2006

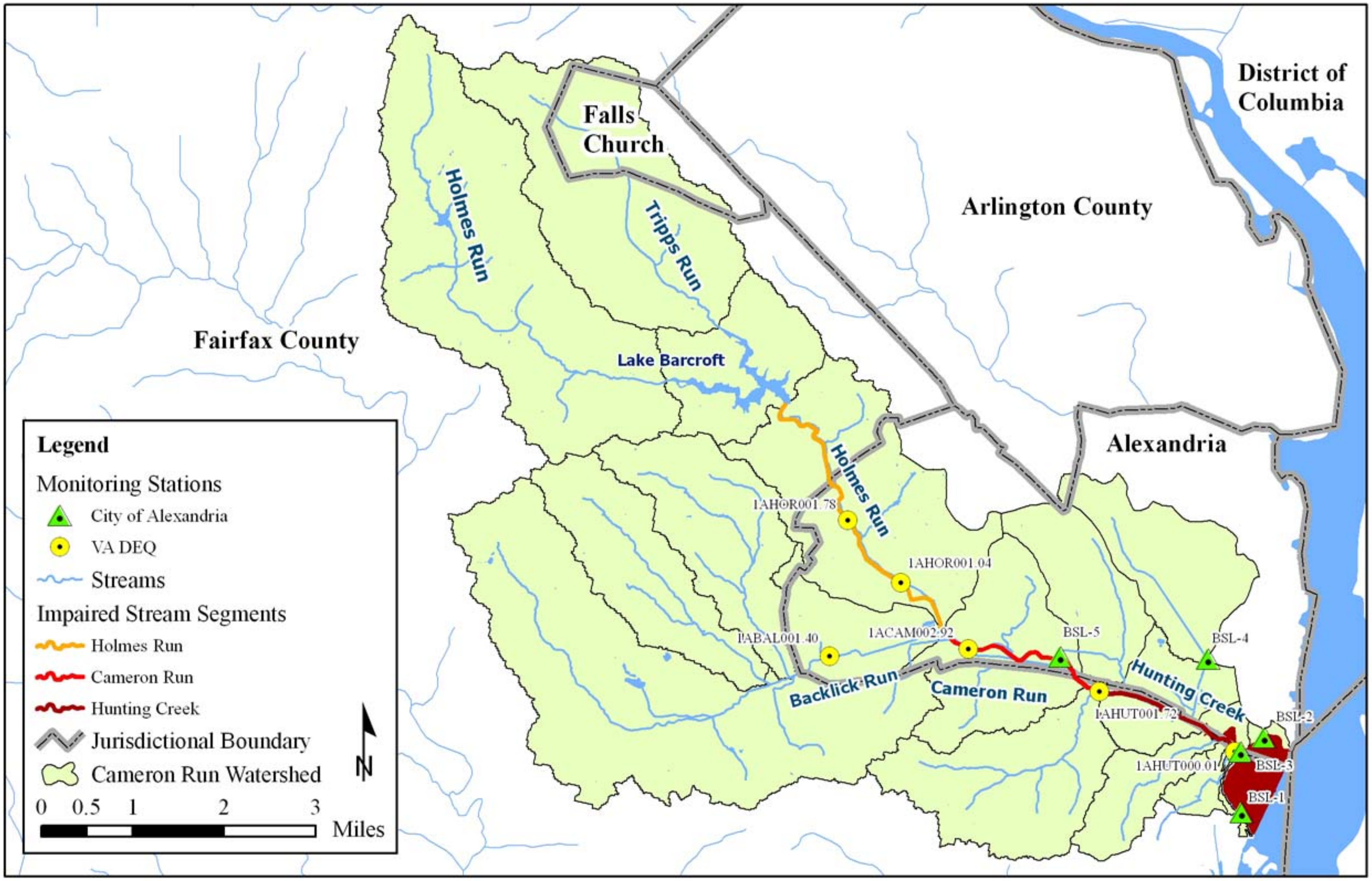


Figure 3-3: Holmes Run, Cameron Run, and Hunting Creek Water Quality Monitoring Stations

Table 3-17 lists the water quality sampling period of record and the number and percentage of samples exceeding the water quality standards collected between 1991 and 2008. The stations formatted in bold text are stations located on the bacteria impaired segments. Analysis of the water quality data indicated that exceedances of the fecal coliform criterion ranged between 16 and 36 percent of the maximum criterion of 400 cfu/100 ml. Since four or more weekly samples were not collected within a calendar month at these stations, geometric mean exceedances could not be calculated.

Table 3-17: VADEQ Fecal Coliform Data in the Holmes Run, Cameron Run, and Hunting Creek

Station	Date Range	No. of Samples	Min. (cfu/ 100mL)	Max. (cfu/ 100mL	Avg. (cfu/ 100mL	Maximum Criterion Exceedances	
						No.	%
1AHUT000.01	4/1991 – 5/2008	124	25	8000	866	45	36
1AHUT001.72	1/2006 – 12/2006	11	50	1100	327	3	27
1ACAM002.92	8/2001 – 5/2008	29	25	2000	306	6	21
1AHOR001.04	8/2001 – 11/2006	8	100	900	300	2	25
1AHOR001.78	4/1991 – 6/2001	38	20	3000	356	6	16
1ABAL001.40	4/1991 – 11/2006	44	20	5400	594	12	27

Four stations within the watershed were sampled between 1991 and 2008 for *E. coli* bacteria. **Table 3-18** lists the water quality sampling period of record, the number of samples, the minimum, maximum and average concentrations observed, and the number and percentage of samples exceeding the water quality standards. All of the stations showed at least one exceedance of the maximum criterion during the period of sampling. Since four or more weekly samples were not collected within a calendar month at these stations, geometric mean exceedances could not be calculated.

Table 3-18: VADEQ E. Coli Data in the Holmes Run, Cameron Run, and Hunting Creek Watersheds

Station	Date Range	No. of Samples	Min. (cfu/ 100mL)	Max. (cfu/ 100mL)	Avg. (cfu/ 100mL)	Maximum Criterion Exceedances	
						No.	%
1AHUT000.01	4/1991 – 5/2008	35	10	200000	6130	15	43
1AHUT001.72	1/2006 – 12/2006	11	50	600	191	3	27
1ACAM002.92	8/2001 – 5/2008	27	10	2000	199	6	22
1AHOR001.04	8/2001 – 11/2006	11	1	274	114	3	27
1ABAL001.40	4/1991 – 11/2006	10	1	280	54	1	10

3.4.2 City of Alexandria Monitoring Stations

The City of Alexandria (COA) has performed water quality monitoring in Cameron Run and Hunting Creek at five locations as part of their permit requirements for their Combined Sewer System (Permit Number VA0**087068)**. Samples were collected starting in 2002. **Table 3-19** lists the stations where COA collected bacteria data. **Figure 3-3** shows the location of the stations.

COA's monitoring program is oriented towards measuring the impact of CSOs on water quality. Two of the stations, BSL-4 and BSL-5, are in non-tidal waters and are intended to represent conditions uninfluenced by CSOs. The other three stations are in tidal waters. A high proportion of the samples were collected during storm events when CSOs are expected to occur. **Table 3-20** shows summary statistics for observed fecal coliform concentrations at the COA stations, 2002-2006. **Table 3-21** shows summary statistics for observed *E. coli* bacteria at these stations, collected over the same period. Given the higher proportion of storm samples, the average, maximum, and percent of samples exceeding the maximum criterion are higher for COA stations than for the VADEQ stations.

Table 3-19: COA Hunting Creek Water Quality Monitoring Stations			
Station	**Station Description**	**Stream Name**	**Monitoring Period**
BSL1	Offshore of Belle Haven Marina	Hunting Creek (Tidal)	10/2002 – 6/2006
BSL2	Offshore of CSO Outfall 002	Hunting Creek (Tidal)	10/2002 – 6/2006
BSL3	G. W. Parkway	Hunting Creek (Tidal)	10/2002 – 6/2006
BSL4	Hoofs Run above CSO outfalls	Hooff Run (Non-Tidal)	10/2002 – 6/2006
BSL5	Non-tidal Cameron Run above Telegraph Road	Cameron Run (Non-Tidal)	10/2002 – 6/2006

Table 3-20: COA Fecal Coliform Data Collected in the Hunting Creek Watershed							
Station	**Date Range**	**No. of Samples**	**Min. (cfu/ 100mL)**	**Max. (cfu/ 100mL**	**Avg. (cfu/ 100mL**	**Maximum Criterion Exceedances**	
						No.	**%**
BSL1	10/2002 – 6/2006	102	20	16,000	1,221	57	56
BSL2	10/2002 – 6/2006	102	20	920,000	23,437	62	61
BSL3	10/2002 – 6/2006	102	20	50,000	2,951	63	62
BSL4	10/2002 – 6/2006	98	20	160,000	10,265	81	83
BSL5	10/2002 – 6/2006	102	20	50,000	2,186	51	50

Table 3-21: COA *E. Coli* Data Collected in the Hunting Creek Watershed							
Station	**Date Range**	**No. of Samples**	**Min. (cfu/ 100mL)**	**Max. (cfu/ 100mL)**	**Avg. (cfu/ 100mL)**	**Maximum Criterion Exceedances**	
						No.	**%**
BSL1	10/2002 – 6/2006	101	20	6,870	621	56	55
BSL2	10/2002 – 6/2006	99	20	326,000	12,321	51	52
BSL3	10/2002 – 6/2006	101	20	24,900	1,238	59	58
BSL4	10/2002 – 6/2006	98	20	127,000	5,616	85	87
BSL5	10/2002 – 6/2006	101	20	6,090	728	49	49

3.4.3 VADEQ Bacterial Source Tracking (BST) Data

As part of the TMDL development, Bacterial Source Tracking (BST) sampling was conducted at three locations in the Holmes Run, Cameron Run, and Hunting Creek watershed. The objective of the BST study was to identify potential sources of fecal coliform in the listed segments of the Holmes Run, Cameron Run, and Hunting Creek watershed.

There are various methodologies used to perform BST, which fall into three major categories: molecular, biochemical and chemical. Molecular (genotype) methods are referred to as “DNA fingerprinting,” and are based on the unique genetic makeup of different strains, or subspecies, of fecal coliform bacteria. Biochemical (phenotype) methods are based on detecting biochemical substances produced by bacteria. The type and quantity of these substances are measured to identify the bacteria source. Chemical methods are based on testing for chemical compounds that are associated with human wastewaters, and are restricted to determining if sources of pollution are human or non-human.

For the Holmes Run, Cameron Run, and Hunting Creek watershed TMDL, the Antibiotic Resistance Analysis (ARA) method of BST was used. ARA has been the most widely used and published BST method to date and has been employed in Virginia, Florida, Kansas, Oregon, South Carolina, Tennessee, and Texas. Advantages of ARA include low cost per sample, and fast turnaround times for analyzing samples. The method can also be performed on large numbers of isolates; typically, 48 isolates per unknown source such as an instream water quality sample.

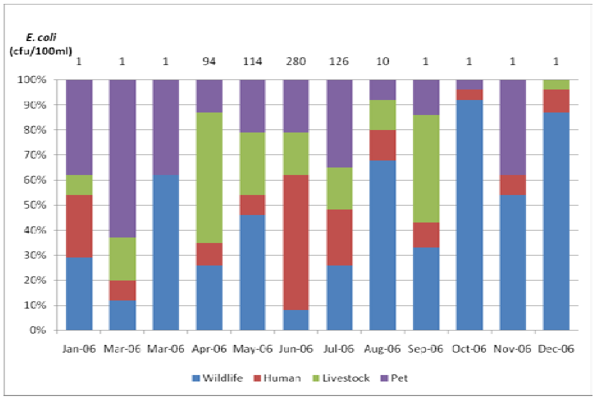
ARA is a biochemical or phenotype method. That is, it is based on an expression of genetic material, resistance to antibiotics, and not an analysis of the molecular structure of genetic material itself, as in the genetic fingerprinting approach. In the ARA method, bacteria samples are tests with a battery of antibiotics. If the bacteria continue to grow after an antibiotic is applied, then the bacteria are resistant to that antibiotic. The patterns of resistance (resistant to amoxicillin, not resistant to ampicillin, etc.) from unknown samples are then compared to the patterns of resistance from a library of known samples. Discriminant analysis, a multivariate statistical technique, is used to classify the sources of bacteria in the unknown samples. Essentially, discriminant analysis determines whether an unknown sample is more similar to known samples in class A than to known samples in class B (or C or D), where a, B, C, and D can be "wildlife," "pets", "human," or "livestock," or some finer or coarser classification scheme. Like any statistical method which recognizes variability in the data, errors are possible. Generally, however, the rate of correct classification using the ARA method is 60 to 80%.

The U. S. EPA's factsheet on BST (USEPA, 2002), provides a nontechnical overview of the different methods. Virginia Cooperative Extension Publication 442-554 (2009) also provides a concise non-technical introduction. An accessible but more technical introduction can be found in the EPA's guidance on the use of BST (USEPA, 2005).

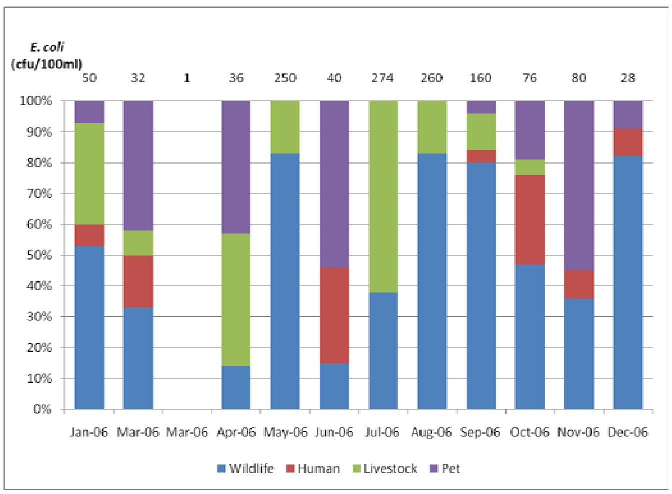
BST was conducted monthly from January 2006 to December 2006 at stations 1ABAL001.40, 1AHOR001.04, and 1AHUT000.01, whose locations were shown in **Figure 3-4**. Four categories of fecal bacteria sources were considered: wildlife, human, livestock and pet. Results from 12 sampling events at each station, are presented in **Table 3-22** and results are depicted in **Figure 3-5**. Results indicate that bacteria from human, livestock, wildlife, and pet sources are present in Holmes Run, Cameron Run, and Hunting Creek. *E. coli* concentrations exceeded the maximum *E. coli* bacteria criterion of 235 cfu/100mL at station 1ABAL001.40 once, at station 1AHOR001.04 three times, and at station 1AHUT001.01 four times out of the 12 samples collected at each station. In terms of percentages, the maximum *E .coli* standard was exceeded up to 33% percent of the time.

Table 3-22: BST Data Collected During 2006 in the Holmes Run, Cameron Run, and Hunting Creek Watershed

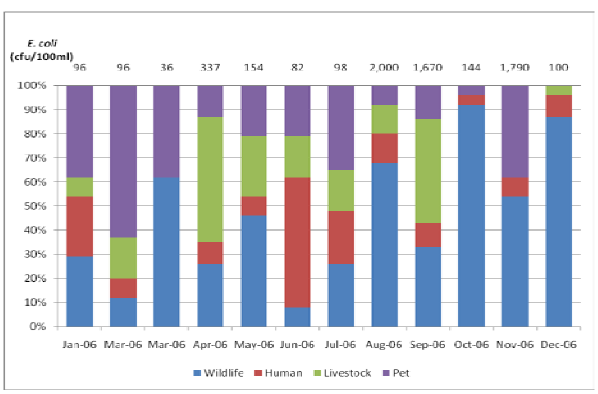
Station ID	Date of Sample	E. coli (cfu/100 mL)	Number of Isolates	Wildlife	Human	Livestock	Pet
1ABAL001.40 1 out of 12 samples (8%) exceed 235 cfu/100mL	1/9/2006	1	NVI	NVI	NVI	NVI	NVI
	3/6/2006	1	NVI	NVI	NVI	NVI	NVI
	3/27/2006	1	NVI	NVI	NVI	NVI	NVI
	4/18/2006	94	24	84%	8%	4%	4%
	5/16/2006	114	24	88%	0%	4%	8%
	6/19/2006	280	21	0%	71%	5%	24%
	7/17/2006	126	23	30%	4%	66%	0%
	8/15/2006	10	2	50%	0%	0%	50%
	9/12/2006	1	NVI	NVI	NVI	NVI	NVI
	10/16/2006	1	NVI	NVI	NVI	NVI	NVI
	11/6/2006	1	NVI	NVI	NVI	NVI	NVI
	12/11/2006	1	NVI	NVI	NVI	NVI	NVI
1AHOR001.04 3 out of 12 samples (25%) exceed 235 cfu/100mL	1/9/2006	50	15	53%	7%	33%	7%
	3/6/2006	32	12	33%	17%	8%	42%
	3/27/2006	1	NVI	NVI	NVI	NVI	NVI
	4/18/2006	36	7	14%	0%	43%	43%
	5/16/2006	250	24	83%	0%	17%	0%
	6/19/2006	40	13	15%	31%	0%	54%
	7/17/2006	274	24	38%	0%	62%	0%
	8/15/2006	260	24	83%	0%	17%	0%
	9/12/2006	160	24	80%	4%	12%	4%
	10/16/2006	76	21	47%	29%	5%	19%
	11/6/2006	80	22	36%	9%	0%	55%
	12/11/2006	28	11	82%	9%	0%	9%
1AHUT000.01 4 out of 12 samples (33%) exceed 235 cfu/100mL	1/9/2006	96	24	29%	25%	8%	38%
	3/6/2006	96	24	12%	8%	17%	63%
	3/27/2006	36	8	62%	0%	0%	38%
	4/18/2006	337	23	26%	9%	52%	13%
	5/16/2006	154	24	46%	8%	25%	21%
	6/19/2006	82	24	8%	54%	17%	21%
	7/17/2006	98	23	26%	22%	17%	35%
	8/15/2006	2,000	24	68%	12%	12%	8%
	9/12/2006	1,670	21	33%	10%	43%	14%
	10/16/2006	144	23	92%	4%	0%	4%
	11/6/2006	1,790	24	54%	8%	0%	38%
	12/11/2006	100	23	87%	9%	4%	0%



Station 1ABAL001.40



Station 1AHOR001.04



Station 1AHUT000.01

Figure 3-4: BST Source Distributions at Stations 1ABAL001.40, 1AHOR001.04, and 1AHUT000.01

3.5 Bacteria Source Assessment

This section focuses on characterizing the sources that potentially contribute to the fecal coliform loading in the Holmes Run, Cameron Run, and Hunting Creek watersheds. These potential sources include permitted facilities, sanitary sewer systems and septic systems, wildlife, and pets. Chapter 4 includes a detailed presentation of how these sources are incorporated and represented in the model.

3.5.1 Permitted Facilities

There are four facilities holding active individual Virginia Pollutant Discharge Elimination System (VPDES) permits, issued through the VPDES permitting program, in the Hunting Creek watershed. The permit number and design flow for each permit are presented in **Table 3-23** and the location is shown in **Figure 3-5**. The Alexandria ASA Advanced Wastewater Treatment Plant (WWTP) and the Alexandria Combined Sewer System (CSS) are major bacteria sources discharging into tidal waters. They will be discussed in more detail below. The permits for Cameron Station and the Carlyle Development are not permitted to discharge bacteria and are not expected to discharge bacteria. They will not be assigned a bacteria wasteload allocation (WLA) under these TMDLs. General permits for domestic sewage discharge are the only general permits authorized to discharge the contaminant of concern. However, there are no general permits for domestic sewage discharge issued in the Hunting Creek watershed.

Table 3-23: Individual VPDES Permitted Facilities within the Holmes Run, Cameron Run, and Hunting Creek Watershed				
Permit No	**Facility Name**	**Receiving Stream**	**Size**	**Category**
VA0025160	Alexandria ASA Advanced Wastewater Treatment Plant	Hunting Creek, Hooff Run	Major	Municipal
VA0087068	Alexandria Combined Sewer System	Hooff Run and Hunting Creek Embayment	Major	Municipal
VA0089109	US Army – Cameron Station	Backlick Run	Minor	Industrial
VA0090107	Carlyle Development II	Cameron Run	Minor	Industrial

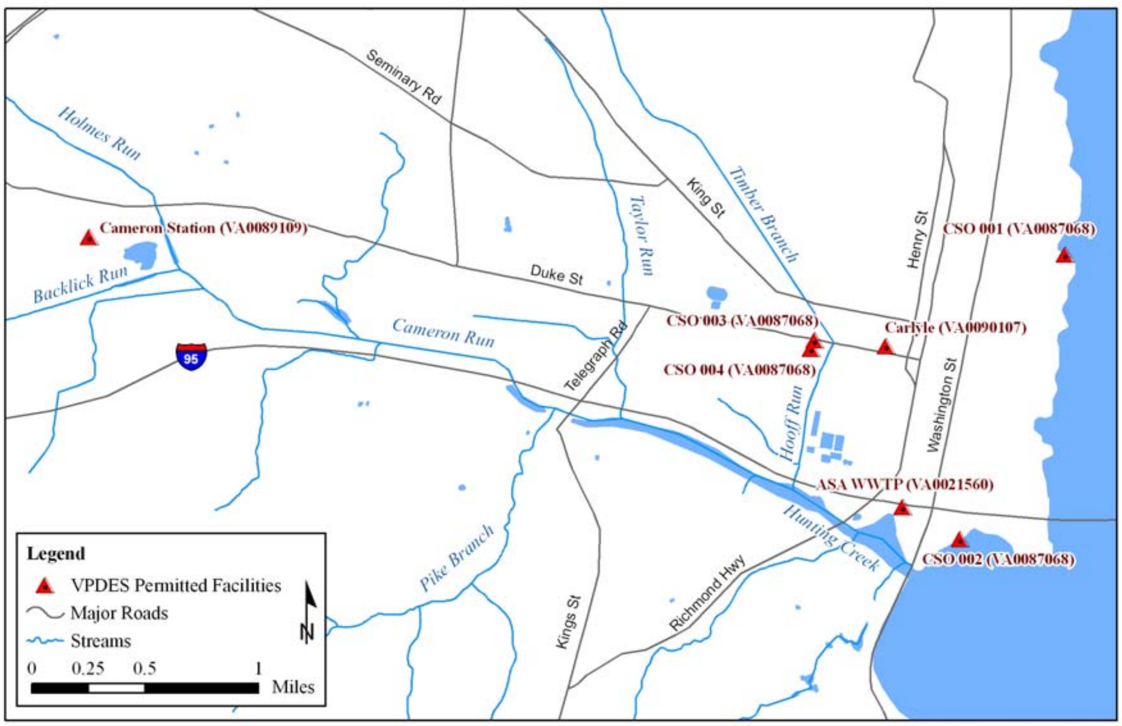


Figure 3-4: Location of Individual VPDES Permitted Facilities in the Hunting Creek Watershed

In addition to the individual permits presented above, Municipal Separate Storm Sewer System (MS4) permits have been issued to cities, counties, and other facilities within the bacteria impaired Holmes Run, Cameron Run, and Hunting Creek watershed. **Table 3-14** lists all the MS4 permit holders in the Holmes Run, Cameron Run, and Hunting Creek watershed.

Table 3-24: MS4 Permits within the Holmes Run, Cameron Run, and Hunting Creek Watershed	
Permit Number	**MS4 Permit Holder**
VA0088579	Arlington County
VA0088587	Fairfax County
VAR040057	City of Alexandria
VAR040062	Virginia Department of Transportation - Northern Urban Area
VAR040065	City of Falls Church
VAR040104	Fairfax County Public Schools
VAR040111	George Washington Memorial Parkway

Alexandria ASA Advanced Wastewater Treatment Plant

The Alexandria Sanitation Authority's (ASA) Alexandria Advanced Wastewater Treatment Plant is a major municipal facility discharging into tidal Hunting Creek downstream of the confluence of Hunting Creek and Hooff Run. The ASA was created by the city and charted by the state. It owns and operates the Alexandria WWTP. Alexandria WWTP has a capacity of 54 million gallons per day (MGD). 32.4 MGD, or 60% of that capacity, is allocated to Fairfax County; the remaining 21.5 MGD, or 40% of capacity, is reserved for COA (COA, 2001).

Table 3-25 gives summary statistics for daily flow, fecal coliform bacteria concentrations, and *E. coli* bacteria concentrations monitored in the effluent from Alexandria WWTP, January 2000 through June 2009. Samples were analyzed for fecal coliform bacteria up until February 2004 and *E. coli* bacteria thereafter. The data was taken from the Discharge Monitoring Reports (DMR) that ASA must submit each month under its permit. As Table 3-25 shows, on average Alexandria WWTP discharges at only about two-thirds of its capacity. Monitored bacteria concentrations are low. Except for a brief period in September and October 2001, reported average monthly fecal coliform concentrations were generally below 80 cfu/ 100 ml, with more than 75 percent of the monthly concentrations below 20 cfu/100 ml. Average monthly *E. coli* concentration are no greater than 6 cfu/ 100 ml, with more than 75 percent of the average monthly concentrations less than 1 cfu/ 100 ml.

Table 3-25: Summary Statistics for Alexandria Sanitation Authority's Advanced Wastewater Treatment Plant

Statistic	Flow (MGD)	Fecal coliform (cfu/ 100 ml)	E. coli (cfu/ 100 ml)
Period	1/2000-6/2009	1/2000-2/2004	2/2004-6/2009
Minimum	29.0	1	<1
Maximum	50.1	434	<6
Mean	36.3	25.4	1
Median	36.3	7	1
25th percentile	32.7	2	1
75th percentile	38.7	19	1

Alexandria Combined Sewer System

Alexandria's Combined Sewer System (CSS) covers approximately 560 acres, mostly in the "Old Town" area of Alexandria (COA, 2001). **Figure 3-5** shows the extent of the CSS. The CSS has four outfalls, also shown in Figure 3-5. All but the Pendleton Street Outfall (001) discharge into the Hunting Creek watershed.

As required by EPA and DEQ regulations, COA has developed a Long-Term Control Plan (LTCP) for the CSS. To develop the LTCP, COA performed extensive monitoring of flows and pollutant concentrations at all four CSO outfalls as well as the five receiving water monitoring locations discussed in Section 3.4.2. A SWMM model of the CSSs was developed from the monitoring data. Computer simulation models of receiving waters—Hunting Creek, Hoof Run, and Oronoco Bay—were also developed by COA and its consultants. The LTCP was approved in 1999. It calls for COA to implement the Nine Minimum Controls (NMC) required by the EPA for all CSS, but to implement no major structural changes such as sewer separation beyond the NMC. COA is required by its permit to continue collecting monitoring data both at the outfalls and in the receiving waterbodies, and to continue to simulate CSO volumes using the SWMM model.

Table 3-26 shows the annual flows by outfall simulated by the SWMM model. Annual flows are relatively small, compared to Alexandria WWTP or non-tidal Cameron Run. **Table 3-27** shows the event mean concentration of fecal coliform bacteria by outfall, based on monitoring data collected by COA 2002-2009. The event mean concentration is essentially the flow-weighted average of observed bacteria concentrations. As Table 3-27 shows, fecal coliform bacteria concentrations are typically in the range 100,000 cfu /100 ml or greater, several orders of magnitude greater than the average fecal coliform concentrations observed in either Alexandria WWTP outfall or in the non-tidal streams draining to Hunting Creek.

Table 3-26: City of Alexandria Simulated CSO Flows (MG)

Year	CSO 1	CSO 2	CSO 3	CSO 4	Total Flow
2001	27.1	33.4	22.3	0.1	82.9
2002	33.3	43.1	28.6	0.1	105.1
2003	69.3	120.2	56.4	8.6	254.5
2004	40.8	74.1	34.8	0.9	150.6
2005	44.3	80.7	36.8	0.1	161.9

Table 3-27: Alexandria CSO Event Mean Concentrations (cfu/ 100 ml) of Fecal Coliform Bacteria

CSO 1	CSO 2	CSO 3	CSO 4
490,848	301,637	153,514	649,186

3.5.2 Population, Number of Households, Sewers, and Septic Systems

Estimates of the number of households per sub watershed were based on year 2000 U.S. Census Bureau blockgroup data. Spatial data were downloaded from http://www.census.gov/geo/www/tiger (release date: December 8, 2008), and the corresponding tabular data was obtained from http://factfinder.census.gov. The aerial extent of blockgroups located within or intersecting a subwatershed were determined using routine GIS analysis. The fraction of each census blockgroup within a subwatershed was calculated and then used to obtain an area-weighted number of households for each watershed. A summary of the population and household estimates for Holmes Run, Cameron Run, and the Hunting Creek drainage are presented in **Table 3-28**.

Table 3-28: 2008 Census Data Summary for Holmes Run, Cameron Run, and Hunting Creek Watershed		
County	**Population**	**Households**
Holmes Run	87,480	34,565
Cameron Run	165,973	65,115
Hunting Creek	196,574	79,501

Source: U.S. Census Bureau (2008)

Extent of Sewer System and Sanitary Sewer Overflows

The Cameron Run watershed has been heavily developed since the 1970's. The entire watershed is sewered. Less than 1% of the households in the Fairfax County portion of the watershed are serviced by septic systems, and there are no septic systems in either Falls Church or the City of Alexandria.

A perfectly functioning sanitary sewer system would convey household wastes from their place of origin to a wastewater treatment plant. Chronic or episodic leaks in the sewer system can occur, however, resulting in the discharge of sewage to the environment. These discharges are called "sanitary sewer overflows (SSOs)."

SSOs are required to be reported to VADEQ. An analysis of reported SSOs in the Cameron Run watershed taken from VADEQ's Pollution Response Program database suggests that SSOs occur in the Cameron Run watershed at a frequency of about 10 per year, and each SSO averages about 2,000 gallons.

Septic Systems and Septic System Failures

Estimates of the number of septic systems in the Cameron Run watershed in Fairfax County were supplied by the Fairfax County Health Department (Joye, 2009). Spatial data that showed properties with septic systems were intersected with the subwatershed polygons using GIS tools. When a property was bisected, it was assigned to the watershed that contained its largest area. There are an estimated 221 septic systems in the entire Hunting Creek drainage, 97 of which are in the Holmes Run watershed and 221 in the Cameron Run watershed. There are no septic systems in Falls Church, the City of Alexandria, or the Belle

Haven portion of Fairfax County. There are also no known straight pipes in the watershed and it is assumed that given the density of development, there are none.

In order to determine the amount of fecal coliform contributed by human sources, the failure rates of septic systems must be estimated. Septic system failures are generally attributed to the age of a system. For this TMDL model, the failure rate was assumed to be 1.62 percent of the total septic systems in the watershed, based on the Upper Accotink Creek Bacteria TMDL (VADEQ, 2002). In order to determine the load of bacteria from these sources, it was assumed that the septic system design flow is 75 gallons per person per day (Horsley and Whitten, 1996). In addition, it was estimated that typical fecal coliform concentrations from a failed septic system is 10,000 cfu/100mL (Horsley and Whitten, 1996).

3.5.3 Wildlife

Wildlife contributions of fecal coliform can be both indirect and direct. Indirect sources are those that are carried to the stream from the surrounding land from rain and runoff events, whereas direct sources are those that are directly deposited into the stream.

The wildlife inventory for this TMDL was developed based on a number of information and data sources, including: (1) GIS analysis habitat availability, (2) Department of Game and Inland Fisheries (DGIF) harvest data and population estimates, and (3) stakeholder comments and observations.

A wildlife inventory was conducted based on habitat availability within the watershed. The number of animals in the watershed was estimated by combining typical wildlife densities with available stream wildlife habitat. Habitat data and bacteria production rates were obtained through a variety of sources, including previous bacteria TMDL studies conducted in Northern Virginia watersheds, such as Upper Accotink Creek Bacteria TMDL (VADEQ, 2002); studies conducted in other urban areas of the Commonwealth, such as Richmond in James River City of Richmond Bacteria TMDL (VADEQ, 2009); and the recommendations of local wildlife experts. Duck and goose bacteria production rates were obtained from the James River (Richmond Area). Charles Smith of the Fairfax County Parks Department (Smith, 2009) provided updated habitat information for raccoons and beavers, and the goose density figure was reduced from original estimates by 85% based on information provided by David Feld with Geese Peace (Feld, 2009).

Table 3-29: Wildlife Densities		
Wildlife type	**Population Density**	**Habitat Requirements**
Deer[1]	0.12 animals/acre	Entire watershed
Raccoon[1]	0.31 animals/acre	Entire watershed
Muskrat[3]	2.0 animals/acre	Within 30 feet of streams and ponds (urban, grassland, forest, wetlands)
Beaver[2]	4.8 animals/mile of stream	Entire watershed
Goose[4]	0.35 animals/acre	Within 300 feet of streams and ponds (urban, grasslands, wetlands)
Duck[1]	0.06 animals/acre	Within 300 feet of streams and ponds (urban, grasslands, wetlands, forest)

Sources:
[1]*Lower Accotink Creek Bacteria TMDL (VADEQ, 2008c)*
[2]*Neabsco Creek Bacteria TMDL (VADEQ, 2007)*
[3]*Charles Smith, Fairfax County Park Authority (personal communication, 2009)*
[4]*David Feld, Geese Peace (personal communication, 2009)*

The wildlife inventory presented in **Table 3-30** was calculated using the densities from **Table 3-29**, and a GIS analysis of available habitat by subwatershed and land use.

Table 3-30: Estimated Wildlife Population Numbers by Watershed			
Wildlife	**Holmes Run**	**Cameron Run[1]**	**Hunting Creek[2]**
Deer	1,451	2,985	3,483
Raccoon	3,749	7,711	8,998
Muskrat	238	649	782
Beaver	102	250	305
Goose	634	1,624	1,948
Duck	78	199	236

1 *Includes Holmes Run Watershed*
2 *Includes Holmes Run and Cameron Run Watersheds*

The wildlife inventory was used to determine the fecal coliform loading by wildlife within the watershed. Separation of the wildlife daily fecal coliform load into direct and indirect deposits was based on estimates of the amount of time each type of wildlife spends on land versus time spent in the stream. **Table 3-31** shows the average fecal coliform production per animal, per day, contributed by each type of wildlife and the percent of time each type of wildlife spends in the stream on a daily basis.

Table 3-31: Fecal Coliform Production from Wildlife		
Wildlife	**Daily Fecal Production (in millions of cfu/day per animal)**	**Portion of the Day in Stream (%)**
Deer[1]	347	1
Raccoon[1]	113	2.5
Muskrat[1]	25	50
Goose[2]	56.3	50
Beaver[3]	0.3	90
Duck[2]	0.53	75

Sources:
[1] Lower Accotink Creek Bacteria TMDL (VADEQ, 2008c)
[2]James River and Tributaries-City of Richmond (VADEQ, 2010)
[3] Neabsco Creek Bacteria TMDL (VADEQ, 2007)

3.5.4 Pets

The contribution of fecal coliform loading from pets was also examined in the assessment of fecal coliform loading to the Cameron Run Watershed. The two types of domestic pets that were considered as sources of bacteria in this TMDL were cats and dogs. The number of pets residing in the watershed was estimated by determining the number of households in the watershed, and multiplying this number by national average estimates of the number of pets as 0.58 dogs per household and 0.66 cats per household (American Veterinary Medical Association, 2007). Table 3-32 shows the population of cats and dogs by watershed.

Table 3-31: Pet Populations		
Watershed	**Dogs**	**Cats**
Holmes Run	20,048	22,813
Cameron Run[1]	37,767	42,976
Hunting Creek[2]	46,111	52,471

1 *Includes Holmes Run Watershed*
2 *Includes Holmes Run and Cameron Run Watersheds*

The fecal coliform load was estimated based on daily fecal coliform production rate of 2.98 $x10^{8}$ cfu/day per cat and 1.85 $x10^{9}$ cfu/day per dog (Moyer and Hyer, 2003).

4 Modeling Approach

Establishing the relationship between in-stream water quality and the source loadings is a critical component of TMDL development. It allows for evaluation of management options that will achieve the desired water quality endpoint. In the development of bacteria TMDLs for Holmes Run, Cameron Run and Hunting Creek, the relationship was defined through computer modeling based on data collected throughout the watershed. Monitored flow and water quality data were then used to verify that the relationships developed through modeling were accurate.

Computer simulation modeling primarily plays three roles in bacteria TMDL development. First, computer simulation models are used to determine the loading rates (bacteria per day) that enter the impaired waterbody from nonpoint sources. The source assessment quantifies how much bacteria is deposited on the land surface by wildlife or pets. How much of that bacteria enter the waterbody is a function of the runoff or subsurface flow that transports the bacteria deposited on the surface into the river or stream. By modeling the fate and transport of bacteria through the hydrological cycle, models can determine the bacteria loads from nonpoint sources.

Second, models represent the link between bacteria input loads and the bacteria concentrations observed in the impaired waterbody. Model calibration determines how well the model represents the fate and transport of bacteria in the waterbody. In calibration, model parameters are adjusted until there is a good fit between observed and simulated values of flows, temperature, or bacteria concentrations.

Third, the calibrated model is used to predict the bacteria concentrations that would occur under lower loading rates. In particular, the calibrated model is used to determine what input loads from which sources are compatible with water quality standards for bacteria. These input loads form the basis of the loading capacity of the waterbody expressed as the TMDL. The TMDL is comprised of load allocations (LAs) for non-point sources of bacteria, and wasteload allocations (WLAs) for point source loadings.

Hydrological Simulation Program Fortran (HSPF) is the computer model used not only to develop the TMDLs for non-tidal Holmes Run and Cameron Run, but also to estimate bacterial loads from other portions of the watershed draining to tidal Hunting Creek. HSPF is the standard model use to develop bacteria TMDLs in Virginia's rivers and streams. It is not capable, however, of simulating tidally-influence waters. The Euler-Lagrangian Circulation (ELCIRC) model was chosen to simulate the fate and transport of bacteria in tidal Hunting Creek. ELCIRC is a two- or three- dimensional continuous simulation model developed to represent the hydrodynamics and water quality of tidal waters such as embayments, estuaries, or waters off the continental shelf (Zhang *et al*., 2004; Baptista *et al*., 2005). It uses a semi-implicit finite-difference, finite-volume approach to solve shallow water equations on an orthogonal unstructured grid. An Euler-Lagrangian advection scheme is used to solve the momentum and water quality equations to overcome the limitations of the Courant-Friedrichs-Lewy (CFL) condition. This allows ELCIRC to represent relatively small grid sizes (as small as a few meters) using a relatively large time step (on the order of five minutes). ELCIRC is also capable of representing the dynamics of wetting and drying in tidal flats which occur in Hunting Creek.

Following the standard practice of Virginia bacteria TMDLs, fecal coliform bacteria, rather than *E. coli* bacteria, were simulated in both models. VADEQ's translator equation, found below, was used to compare simulated fecal coliform bacteria concentrations to Virginia's *E. coli* water quality standards:

E. coli conc. (cfu/100 mL) = 2-0.0172 x [fecal coliform conc. (cfu/100mL)] 0.91905

Section 4.3 describes how fecal coliform loads were converted to *E. coli* loads to calculate the TMDL, LAs and WLAs.

4.1 The HSPF Model of the Cameron Run/Hunting Creek Watershed

4.1.1 Overview of the HSPF Model

HSPF simulates the fate and transport of pollutants over the entire hydrological cycle. Two distinct sets of processes are represented in HSPF: (1) processes that determine the fate and transport of pollutants at the surface or in the subsurface of a watershed, and (2) instream processes. The former will be referred to as land or watershed processes, the latter as in-stream or river reach processes.

Constituents can be represented at various levels of detail and simulated both on land and for in-stream environments. These choices are made in part by specifying the modules that are used, and thus, the choices that are made can establish the model structure used for any one problem. In addition to the choice of modules, other types of information must be supplied for the HSPF calculations, including model parameters and time-series of input data. Time-series of input data include meteorological data, point sources, reservoir information, and other type of continuous data needed for model development.

A watershed is subdivided into model segments, which are defined as areas with similar hydrologic characteristics. Within a model segment, multiple land use types can be simulated, each using different modules and different model parameters. There are two general types of land uses represented in the model: pervious land, which uses the PERLND module, and impervious land, which uses the IMPLND module. More specific land uses, like forest, crop, or developed land, can be implemented using these two general types. In terms of simulation, all land processes are computed for a spatial unit of one acre. The number or acres of each land use in a given model segment is multiplied by the values (fluxes, concentrations, and other processes) computed for the corresponding acre. Although the model simulation is performed on a temporal basis, land use information does not change within the modeled time period.

Within HSPF, the RCHRES module sections are used to simulate hydraulics of river reaches and the sediment transport, water temperature, and water quality processes that result in the delivery of flow and pollutant loading to a bay, reservoir, ocean or any other body of water. Flow through a reach is assumed to be unidirectional. In the solution technique of normal advection, it is assumed that simulated constituents are uniformly dispersed throughout the waters of the RCHRES; constituents move at the same horizontal velocity as the water, and the inflow and outflow of materials are based on a mass balance. HSPF primarily uses the "level pool" method of routing flow through a reach. Outflow from a free-flowing reach is a single-valued function of reach volume, specified by the user in an F-Table, although within a time step, the HSPF model uses a convex routing method to move mass flow and mass within the reach. Outflow may leave the reach through as many as five possible exits, which can represent water withdrawals or other diversions.

Fecal coliform bacteria from PERLND land uses were simulated using the PQUAL module. The PQUAL module simulates the buildup, decay, and washoff of constituents from the surface. Subsurface transport is not modeled, although a constituent concentration can be associated with baseflow (AOQC) or interflow (IOQC). For bacteria, the buildup rate (ACQOP) is determined from the population per acre and bacteria production rate for each species inhabiting the land use. The decay rate is input into the model as the maximum amount of bacteria that can be accumulated on the surface (SQOLIM). The washoff rate (WSQOP) determines how much of the bacteria accumulated on the land surface is removed in runoff. All of these parameters can vary monthly although only SQOLIM varies monthly in the non-tidal HSPF model. Bacteria are modeled in the same way on impervious surfaces, except there is no bacteria concentration associated with interflow or baseflow, since only surface flows occur on impervious surfaces.

4.1.2 HSPF Model Watershed Delineation and Model Segmentation

Delineations of subwatersheds in the Cameron Run/ Hunting Creek drainage were determined from the National Hydrological Database (NHD).

Figure 4-1 shows the delineation of subwatersheds in the Cameron Run HSPF Model.

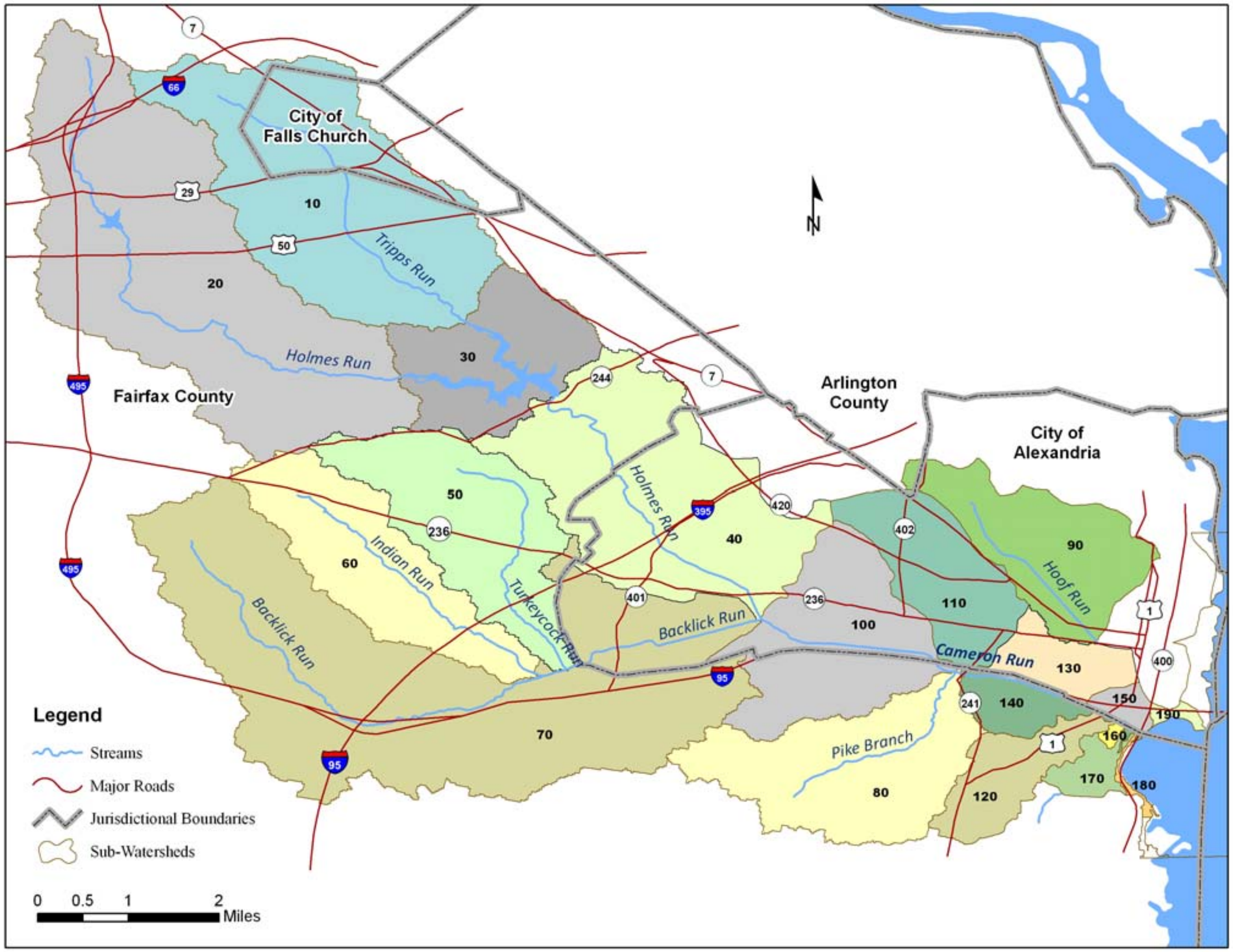


Figure 4-1: Segmentation of the Cameron Run HSPF Model

4.1.3 Land Use

Modeled land uses were taken directly from the land use analysis in Section 3.2.3. Except for residential land uses, zoning land uses were combined into broader categories. The following seven land uses were simulated in the Cameron Run HSPF Model:

- Open Space
- Low Density Residential
- Medium Density Residential
- High Density Residential
- Commercial
- Industrial
- Transportation

Table 3-6 shows which zoning-based land use classifications were combined in the modeled land uses. **Table A-1** in Appendix A shows the acres of pervious land use by segment and land use type, and **Table A-2** in Appendix A shows the acres of impervious land use by segment type.

4.1.4 Meteorological Inputs

The simulation of the hydrological cycle in HSPF, if it includes snow, snowpack, and snowmelt, requires hourly input time series of precipitation, air temperature, dew point temperature, cloud cover, wind speed, and solar radiation. All input precipitation time series were taken from the Chesapeake Bay Program's Phase 5 Watershed Model, Fairfax County segment (A54), except for the hourly precipitation time series, which was taken from data collected at Reagan National Airport (COOP ID 448906).

The Phase 5 temperature data is based on a regional regression of available data against latitude, longitude, and elevation. EPA (2008) explains the methodology in detail. The data has been prepared on a county-by-county basis. Fairfax County meteorological data was used for all watersheds. Potential evapotranspiration in the Phase 5 Model is calculated using the Hamon method from the Phase 5 temperature time series. Other time series in the CBP meteorological data set were taken from hourly observations at Dulles Airport in Herndon, VA. Additional documentation of the development of meteorological time series for the Phase 5 Model can be found through EPA (2008).

4.1.5 F-Tables

F-Tables give the relation between reach volume, and outflow, depth, and surface area. F-Tables for all segments except Segment 30, Lake Barcroft, were constructed for each reach added using the methodology developed by the USGS for the Phase 5 Model (Moyer and Bennett, 2007). The USGS methodology calculates F-Tables based on watershed size and geomorphic region. It is based on a statistical relationship determined between stage and flow collected at USGS gages for each geomorphic region.

The F-Table for Lake Barcroft, Segment 30, was based, first of all, on the relation between surface water elevation and discharge shown in **Figure 4-2**. This information was combined with the elevation vs. volume relation provided by the Lake Barcroft Watershed Improvement District (Grant, 2009) to produce the primary F-Table relationship between volume and discharge.

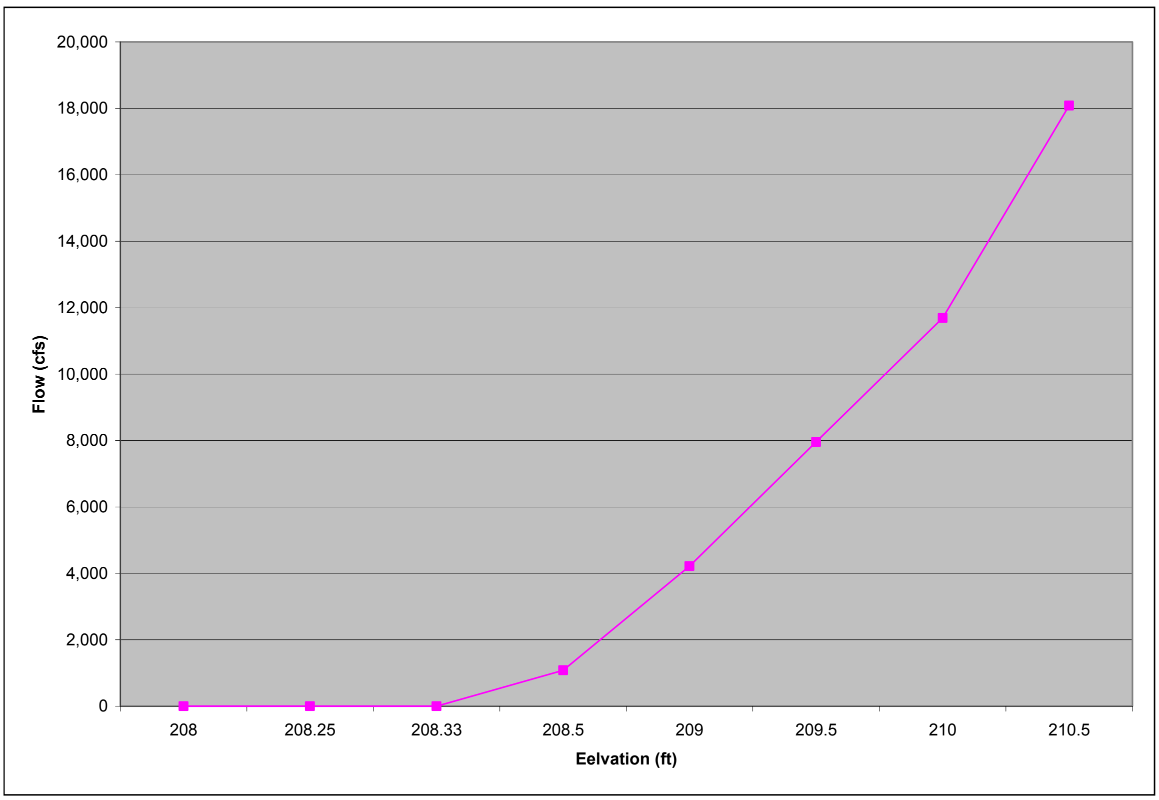


Figure 4-2. Lake Barcroft Discharge-Elevation Relationship, from GKY (1993) cited by Versar (2007)

4.1.6 Hydrology Calibration

The hydrology calibrations were performed using version 5 of PEST, the model-independent parameter estimation software developed by J. Doherty (Doherty, 2001). PEST determines the values of parameters that optimize a user-specified objective function. In these simulations, the objective function was the sum of the squares of the differences between daily observed and simulated flows. This is equivalent to maximizing the coefficient of determination (R^2) between observed and simulated flows.

Table 4-1 gives the key parameters adjusted in hydrology calibration. UZSN, LZETP, and RETSC were allowed to vary monthly. The rest of the parameters were constant throughout the simulation. Other parameters were determined from the CBP Phase 5 Watershed Model's representation of developed land in Fairfax County. Since all land uses represented in the Cameron Run HSPF model are essentially urban land uses, the same set of parameters were used for all land uses.

Table 4-1: Key Hydrology Calibration Parameters

Parameter	Description
LAND_EVAP	PET adjustment (similar to pan evaporation coefficient)
INFILT	Base infiltration rate
LZSN	Lower zone soil moisture storage index
UZSN	Upper zone soil moisture storage index
AGWR	Baseflow recession coefficient
INTFW	Ratio of interflow to surface runoff
IRC	Interflow recession coefficient
LZETP	Evapotranspiration from lower zone storage
RETSC	Impervious surface retention storage
DISCH	Lake Barcroft discharge at 2000 acre-feet volume

The hydrology simulation is extremely sensitive to the Lake Barcroft F-Table, particularly because there is a volume (2000 acre-feet) below which minimal flow is released. The simulated segment does not pass stormflow if the simulated volume in the lake is even slightly below the actual volume. To better simulate stormflow, the discharge at 2000 acre-feet was treated as a calibration parameter.

Daily average flows simulated by the model at the input to Segment 100 (the sum of the outputs from Segment 40 and 70) were compared to the observed daily average flow recorded at USGS gage 0165300 (Cameron Run at Alexandria). The simulation period for the hydrology calibration is 2001-2005. The years 1996-2000 were chosen as the verification period.

Figure 4-3 compares the time series of observed and simulated daily flows at the location of USGS gage 01653000 for the calibration period, 2001-2005. **Figure 4-4** shows a scatter plot of the same information. The coefficient of determination (R^2) between observed and simulated daily flows is 0.76. **Figure 4-5** compares the distribution of daily average flows over the calibration period. **Table 4-2** gives key hydrological statistics for both the simulated and observed daily flows. The errors in the simulated statistics are all within the bounds normally met by HSPF hydrology simulations developed in support of Virginia TMDLs.

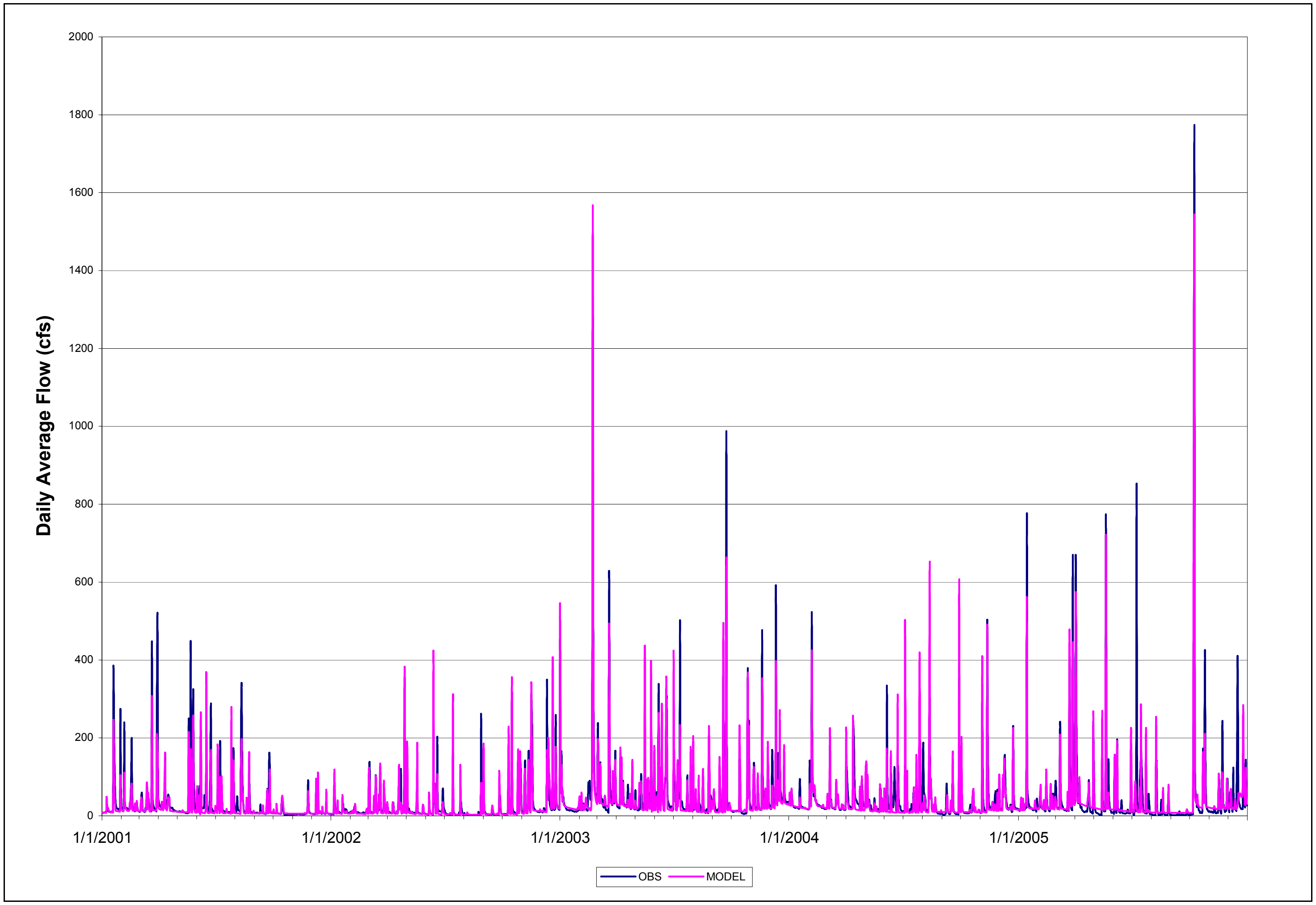


Figure 4-3: Time Series of Simulated and Observed Daily Average Flow, Cameron Run Calibration Period, 2001-2005

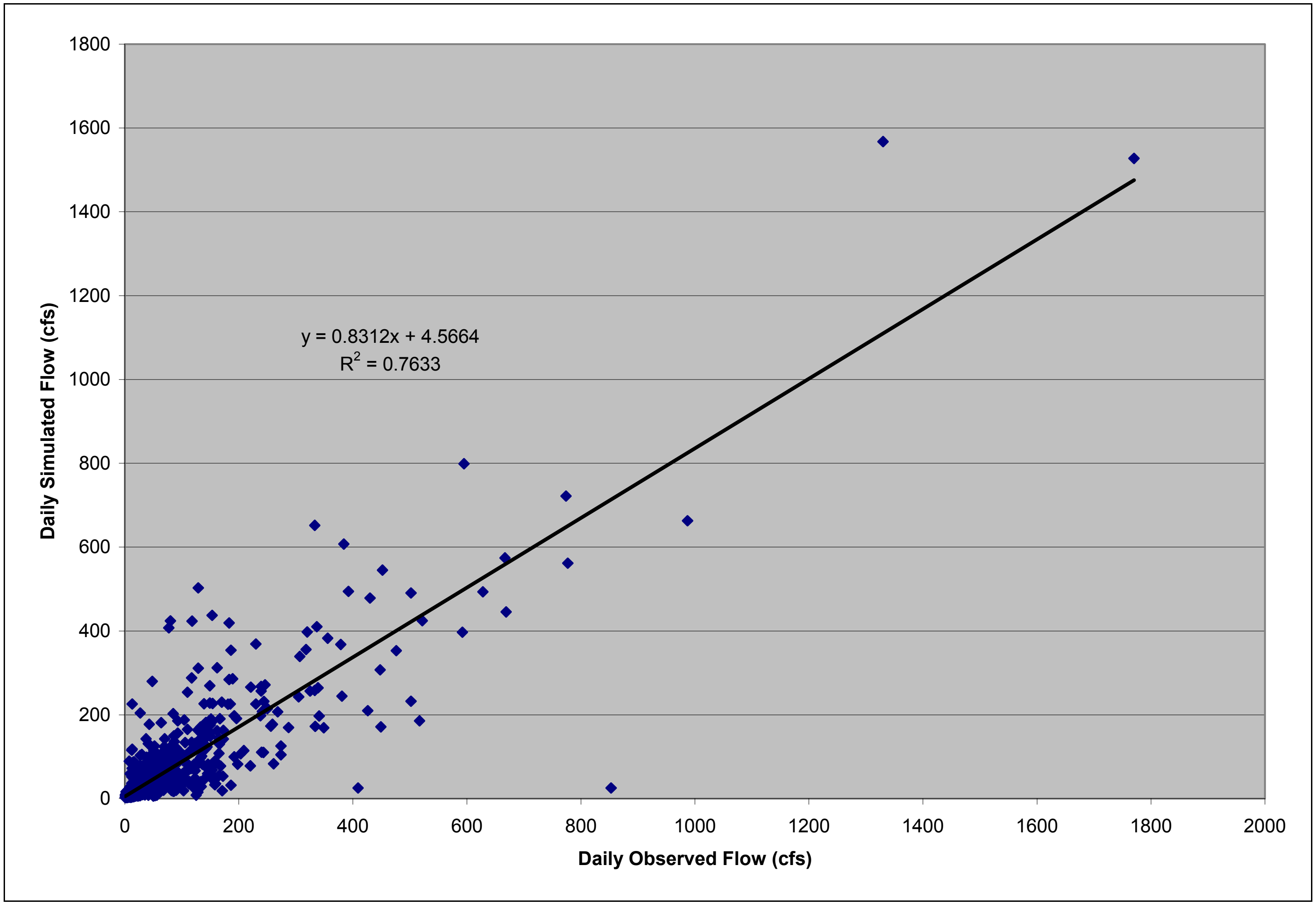


Figure 4-4: Scatter Plot of Simulated and Observed Daily Average Flow, Cameron Run Calibration Period, 2001-2005

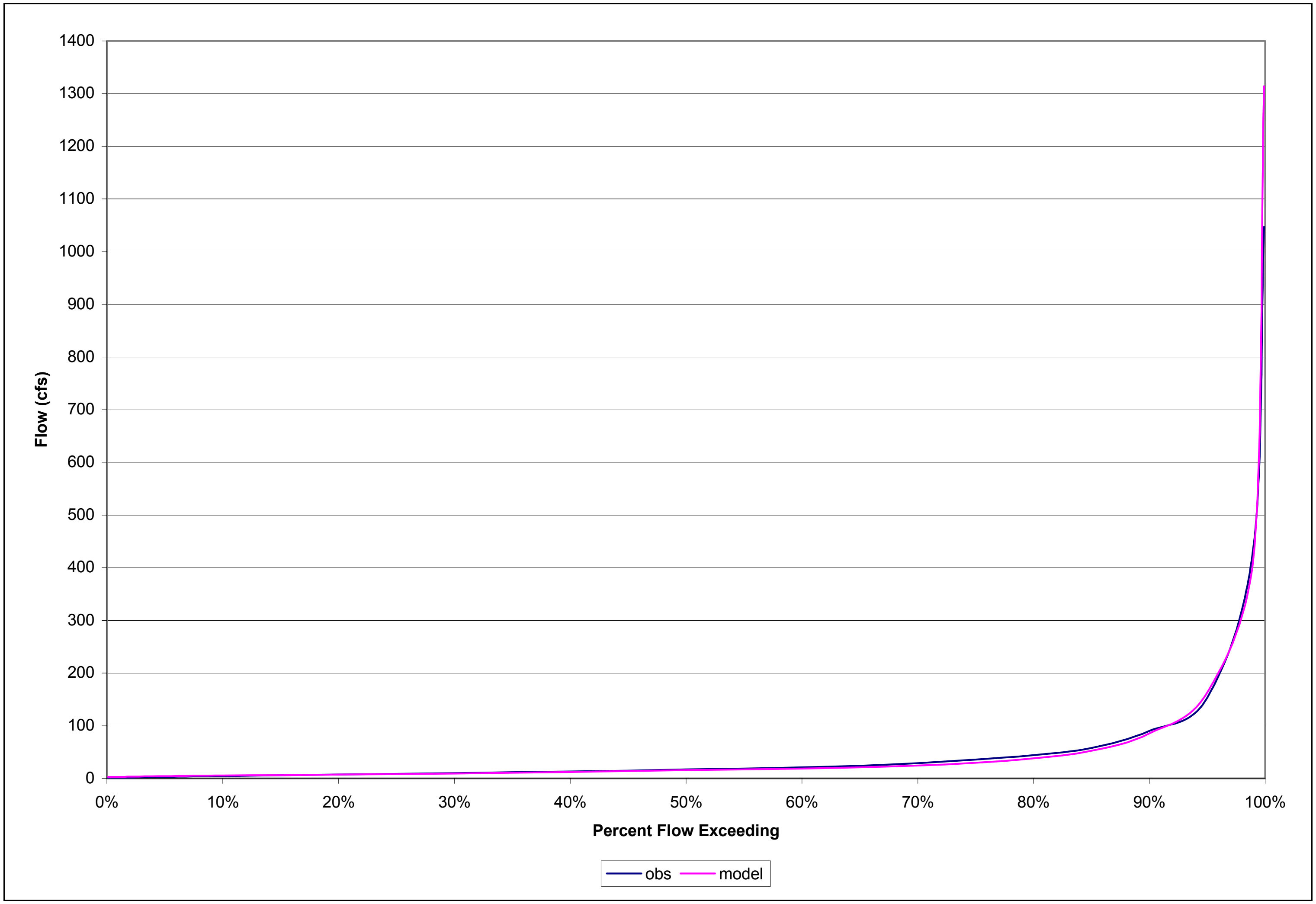


Figure 4-5: Cumulative Distribution Function of Simulated and Observed Daily Average Flow, Cameron Run Calibration Period, 2001-2005

Table 4-2: Observed and Simulated Hydrological Statistics, Calibration Period (2001-2005)				
Statistic	**Observed**	**Simulated**	**Percent difference**	**Criterion**
Total runoff, in inches	83.8	78.9	-6%	± 10%
Total of highest 10% flows, in inches	46.7	45.2	-3%	± 15%
Total of lowest 50% flows, in inches	8.9	8.8	-1%	± 10%
Summer flow volume, in inches	19.1	19.1	0%	± 10%
Winter flow volume, in inches	21.6	19.4	-10%	± 10%

Figure 4-6 compares the time series of observed and simulated daily flows at the location of USGS gage 01653000 for the verification period, 1996-2000. **Figure 4-7** shows a scatter plot of the same information. The coefficient of determination (R^2) between observed and simulated daily flows is 0.74. **Figure 4-8** compares the distribution of daily average flows over the verification period. **Table 4-3** gives key hydrological statistics for both the simulated and observed daily flows. The errors in the simulated statistics are all within the bounds normally met by HSPF hydrology simulations developed in support of Virginia TMDLs.

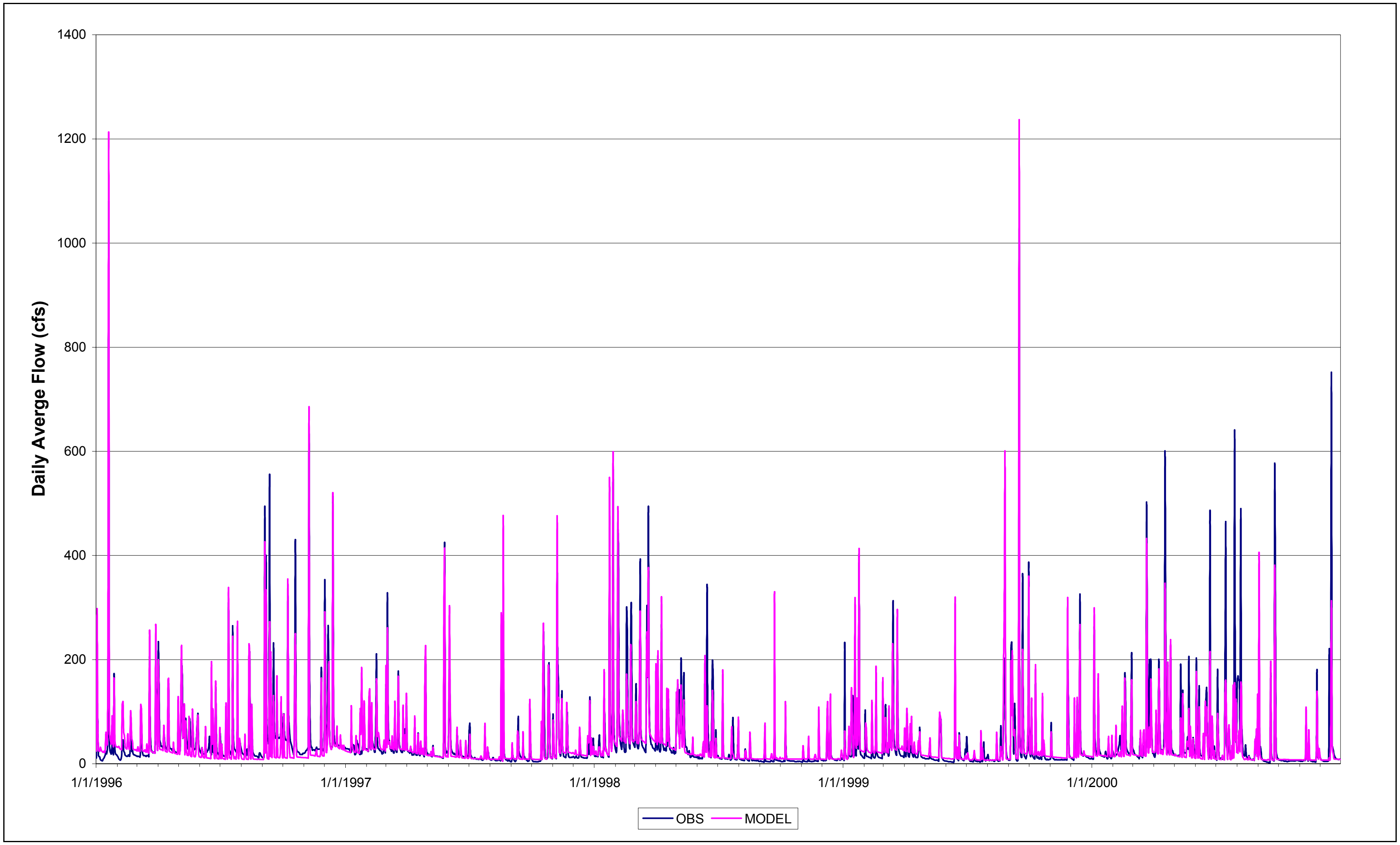


Figure 4-6: Time Series of Simulated and Observed Daily Average Flow, Cameron Run Verification Period, 1996-2000

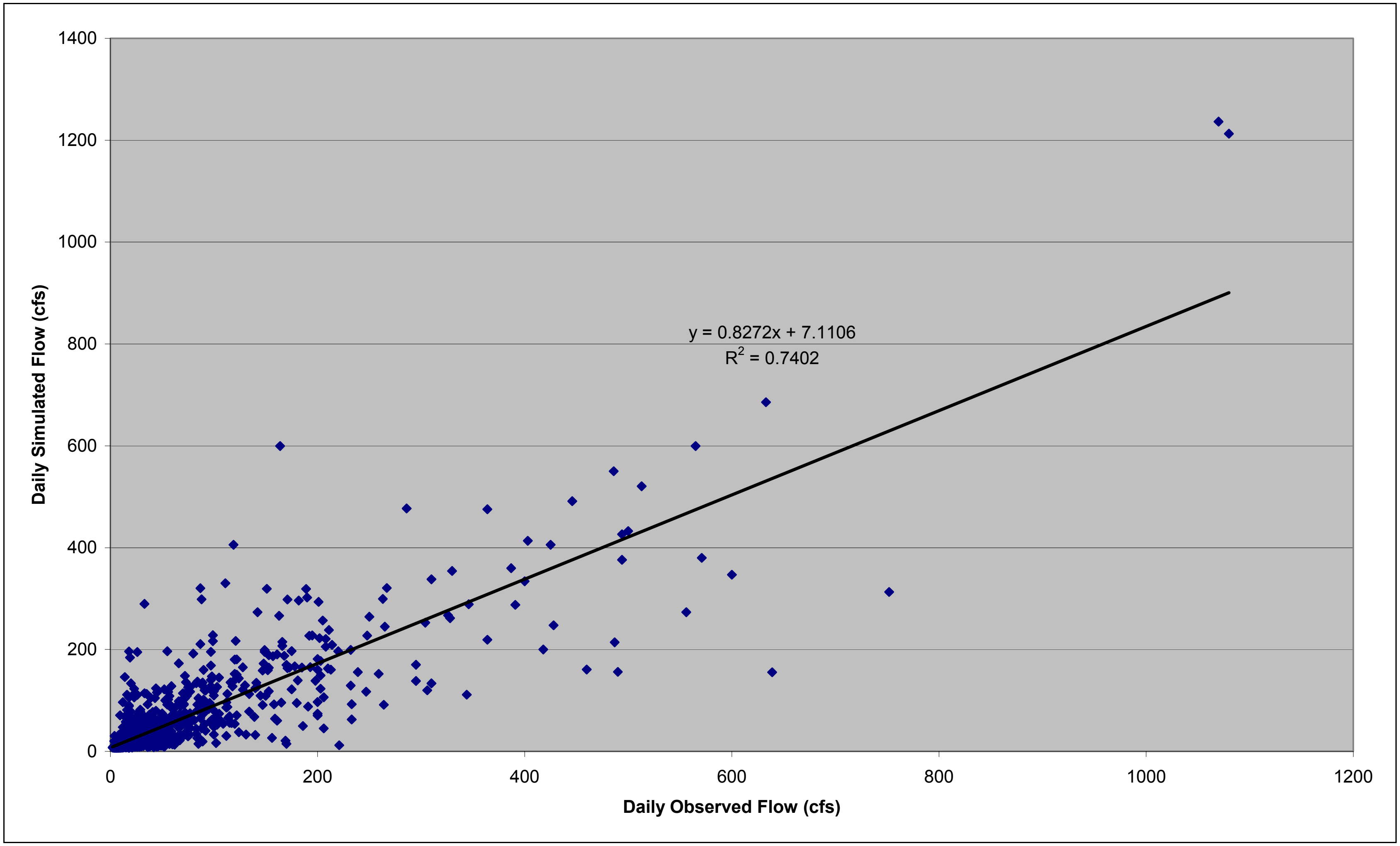


Figure 4-7: Scatter Plot of Simulated and Observed Daily Average Flow, Cameron Run Verification Period, 1996-2000

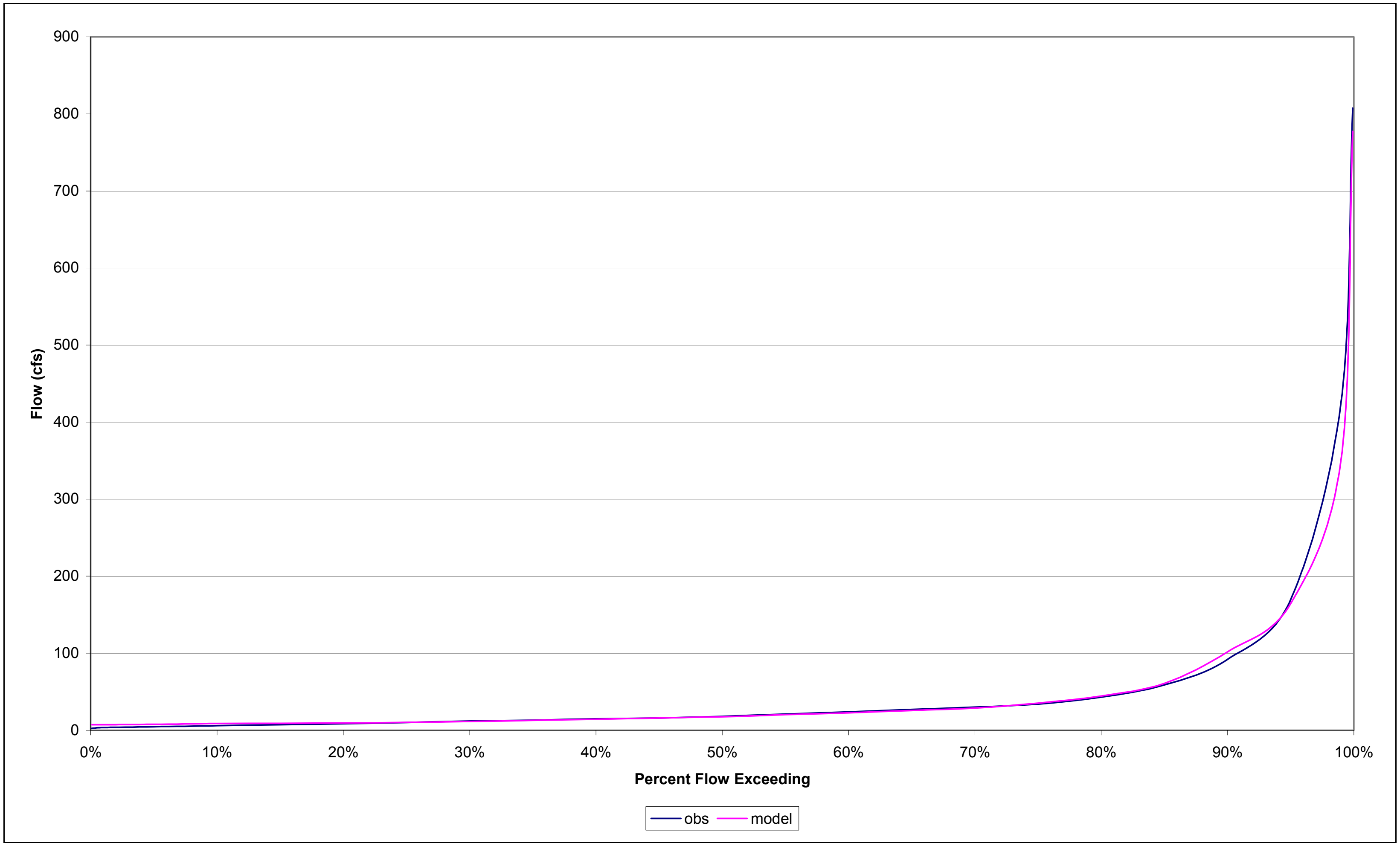


Figure 4-8: Cumulative Distribution Function of Simulated and Observed Daily Average Flow, Cameron Run Verification Period, 1996-2000

Table 4-3: Observed and Simulated Hydrological Statistics, Verification Period (1996-2000)				
Statistic	**Observed**	**Simulated**	**Percent difference**	**Criterion**
Total runoff, in inches	84.2	84.0	0%	± 10%
Total of highest 10% flows, in inches	44.8	43.2	-4%	± 15%
Total of lowest 50% flows, in inches	10.4	11.3	9%	± 10%
Summer flow volume, in inches	17.2	16.1	-7%	± 10%
Winter flow volume, in inches	22.6	24.2	7%	± 10%

Table 4-4 shows the values of the parameters used in the final calibration. The Lake Barcroft discharge at 2000 acre-feet was set at 55.991 cfs, slightly higher than the value derived from the elevation discharge curve.

Table 4-4: Key Parameters in the Cameron Run HSPF Model							
Parameter	**Definition**	**Units**	**Typical**		**Possible**		**Hunting Creek**
			Min	**Max**	**Min**	**Max**	
FOREST	Fraction forest cover	None	0.00	0.5	0	1.0	0.066267
LZSN	Lower zone nominal soils moisture	inch	3	8	0.01	100	2.3890
INFILT	Index to infiltration capacity	Inch/ hour	0.01	0.25	0.0001	100	0.38541
LSUR	Length of overland flow	Ft	200	500	1	None	245
SLSUR	Slope of overland flowpath	None	0.01	0.15	0.00001	10	0.1
KVARY	Groundwater recession variable	1/inch	0	3	0	None	0.627661
AGWRC	Basic groundwater recession	None	0.92	0.99	0.001	0.999	0. .99835
PETMAX	Air temp below which ET is reduced	Deg F	35	45	None	None	40
PETMIN	Air temp below which ET is set to zero	Deg F	30	35	None	None	35
INFEXP	Exponent in infiltration equation	None	2	2	0	10	2
INFILD	Ratio of max/mean infiltration capacities	None	2	2	1	2	2
DEEPER	Fraction of groundwater inflow to deep recharge	None	0	0.2	0	1.0	0.1
BASETP	Fraction of remaining ET from base flow	None	0	0.05	0	1.0	0.00
AGWETP	Fraction of remaining ET from active groundwater	None	0	0.05	0	1.0	0.005
CEPSC	Interception storage capacity	Inch	0.03	0.2	0.00	10.0	0.0
UZSN	Upper zone nominal soils moisture	inch	0.10	1	0.01	10.0	1.008 - 1.68

Table 4-4: Key Parameters in the Cameron Run HSPF Model							
NSUR	Manning's n	None	0.15	0.35	0.001	1.0	0.25
INTFW	Interflow/surface runoff partition parameter	None	1	3	0	None	0.470
IRC	Interflow recession parameter	None	0.5	0.7	0.001	0.999	0.61059
LZETP	Lower zone ET parameter	None	0.2	0.7	0.0	0.999	0.4 - 0.7
ACQOP*	Rate of accumulation of constituent	#/ac day					2.87E09 - 9.36E09
SQOLIM*	Maximum accumulation of constituent	#					2.87E10 – 9.36E10
WSQOP*	Wash-off rate	Inch/ hour					0.1 - 1.0
IOQC*	Constituent concentration in interflow	#/CF					1 – 60,000
AOQC*	Constituent concentration in active groundwater	#/CF					4248 – 53,000
KS*	Weighing factor for hydraulic routing		0.5				0.5
FSTDEC*	First order decay rate of the constituent	1/day	1.152 (FC)				2.0 – 10.0
THFST*	Temperature correction coefficient for FSTDEC	none	1.07				1.04

4.1.7 HSPF Bacteria Calibration Targets

Monitoring data for calibrating the simulation of the fate and transport of bacteria in HSPF was available during the calibration period at five monitoring stations: VADEQ's stations 1AHOR001.04 on Holmes Run (Segment 40), 1ABAL001.40 on Backlick Run (Segment 70), and 1ACAM002.92 on Cameron Run (Segment 100); and the COA's stations B5 on Cameron Run (Segment 100) and B4 on Hooff Run (non-tidal) (Segment 90). **Figure 4-9** shows the location of these stations.

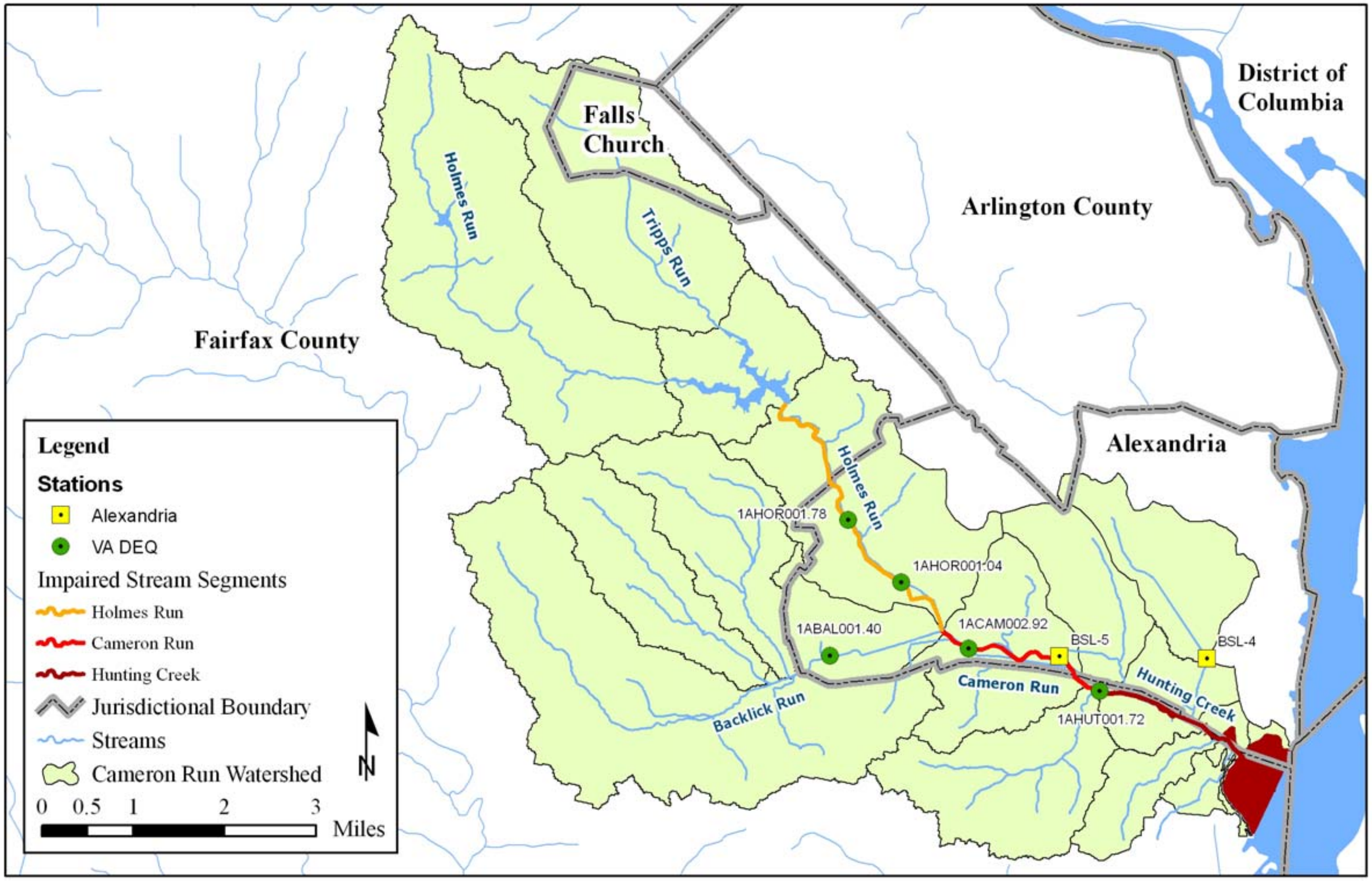


Figure 4-9: Stations Used in Calibration of Cameron Run HSPF Model

The standard calibration targets for bacteria simulations in Virginia TMDLs are (1) the geometric mean of simulated daily average bacteria concentrations should match the geometric mean of the observed data, and (2) the exceedance rate of the maximum *E. coli* criterion of 235 cfu/100 ml of the simulated bacteria concentrations, when converted to *E. coli* concentrations using the VADEQ translator, should match the exceedance rate of the observed data. As discussed in Section 3.4.2, many of the COA's observations were taken during storm events, and observations from storm events are disproportionately represented in the data sets for Cameron Run and Hooff Run. For this reason, a weighted average of stormflow and ambient flow samples was used to calculate the observed geometric mean and exceedance rate at these two locations. The following steps were taken to calculate the geometric mean:

- Flow-percentiles were calculated for daily flows at the Cameron Run gage and monitoring data were classified by the associated flow percentiles. If flow was at or above the 90th percentile flow, it was classified as a storm sample; otherwise, it was classified as an ambient flow sample.
- The logs of the fecal coliform concentrations were calculated, and average values of the logs were calculated for storm and ambient samples.
- The weighted average of the storm and ambient samples were calculated = 0.1*average of storm samples +0.9 * average of ambient samples.
- The weighted average of the logs was transformed back to give the weighted geometric mean of all samples.

Exceedance rate was similarly calculated as a weighted average of storm and ambient transformed *E. coli* concentrations. **Table 4-5** gives the targets for all locations used for the calibration.

Table 4-5: Bacteria Calibration Targets for Cameron Run HSPF Model

Station	Calibration Period (2001-2005)		Verification Period (1996-2000)	
	Geometric Mean	Exceedance Rate	Geometric Mean	Exceedance Rate
Holmes Run	209	0.38	167	0.17
Backlick Run	150	0.25	246	0.28
Cameron Run	269	0.40		
Hooff Run	1423	0.79		

No bacteria sampling took place at either Cameron Run or Hooff Run during the hydrological verification period, 1996-2000. VADEQ collected samples at Backlick Run (Station 1ABAL001.40) and Holmes Run (Station 1AHOR001.78, located upstream of 1AHOR1.04) during the verification period. Table 4-5 gives the geometric mean and exceedance rate for the observed data collected at these two stations from 1996-2000.

4.1.8 HSPF Bacteria Calibration

Fecal coliform bacteria from PERLND land uses were simulated using the PQUAL module. The PQUAL module simulates the buildup, decay, and washoff of constituents from the surface. Subsurface transport is not modeled, although a constituent concentration can be associated with baseflow (AOQC) or interflow (IOQC). For bacteria, the buildup rate (ACQOP) is determined from the population per acre and bacteria production rate for each species inhabiting the land use. **Table A-3** in Appendix A gives the daily buildup rate on pervious land by segment and land use. The decay rate is input into the model as the maximum amount of bacteria that can be accumulated on the surface (SQOLIM). The washoff rate (WSQOP) determines how much of the bacteria accumulated on the surface are removed in runoff. Bacteria are modeled in the same way on impervious surfaces except there is no bacteria concentration associated with interflow or baseflow, since only surface flows occur on impervious surfaces. **Table A-4** in Appendix A gives the daily buildup rate on impervious land by segment and land use. In river reaches, bacteria are represented as a dissolved constituent subject to temperature-dependent, first-order decay.

Table 4-6 summarizes the parameters that were adjusted in the calibration to match the calibration targets discussed in Section 4.1.6. Four distinct sets of parameters were calibrated, corresponding to the four calibration locations. Table 4-6 also shows the segments which received the same set of parameters and the associated monitoring points.

Table 4-6: Bacteria Calibration Parameters for Cameron Run HSPF Model					
Watershed		**Holmes Run**	**Backlick Run**	**Cameron Run**	**Hooff Run**
Segments		**10-40**	**50-70**	**80, 100, 120,140, 160-180**	**90, 110, 130, 150, 190**
Pervious	**Max. Storage (x ACQOP)**	10x	10x	10x	10x
	Washoff Rate	1.0	1.0	1.0	0.1
Impervious	**Max. Storage (x ACQOP)**	3 x	1.2 x	1.5 x	10x
	Washoff Rate	0.005	0.1	0.04	0.02
Reach	**Decay Rate**	2.0	2.0	10.0	10.0

Table 4-7 compares the simulated geometric mean concentrations and exceedance rates with their calibration targets. Simulated means and exceedance rates for Cameron Run and Hooff Run are within 10% of their targets. It should be expected that both the geometric mean and exceedance rates for Holmes Run and Backlick Run are larger than their targets, because the targets for those stations do not have any explicit stormflow monitoring. The targets, in these cases, give a lower bound on the simulation. Simulated bacteria concentrations in Holmes Run are closer to the observed targets because the presence of Lake Barcroft upstream of the monitoring station moderates the distinction between stormflow and baseflow. **Figures 4-10**, **4-11**, **4-12**, and **4-13** compare the time series of simulated bacteria concentrations with observations at Holmes Run, Backlick Run, Cameron Run, and Hooff Run, respectively. **Figures 4-14**, **4-15**, **4-16**, and **4-17** show box plots comparing the distribution of simulated and observed bacteria concentrations in Holmes Run, Backlick Run, Cameron Run, and Hooff Run, respectively.

Table 4-7: Cameron Run HSPF Model Calibration Results (2001-2005)				
Station	**Observed**		**Simulated**	
	Geometric Mean	**Exceedance Rate**	**Geometric Mean**	**Exceedance Rate**
Holmes Run	209	0.38	258	0.39
Backlick Run	150	0.25	169	0.32
Cameron Run	269	0.40	293	0.40
Hoof Run	1423	0.79	1427	0.79

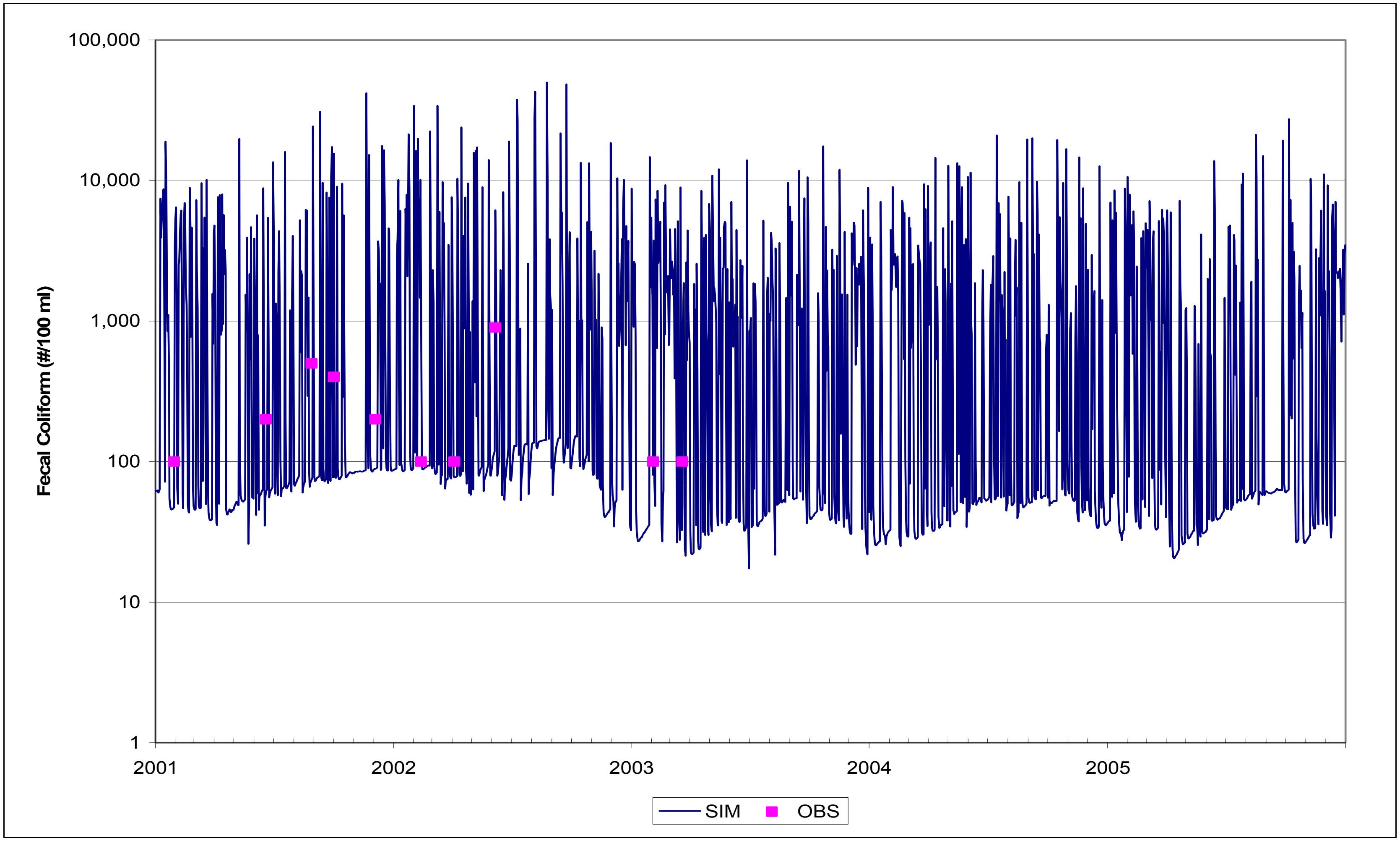


Figure 4-10: Observed and Simulated Bacteria Concentrations, Holmes Run 2001-2005

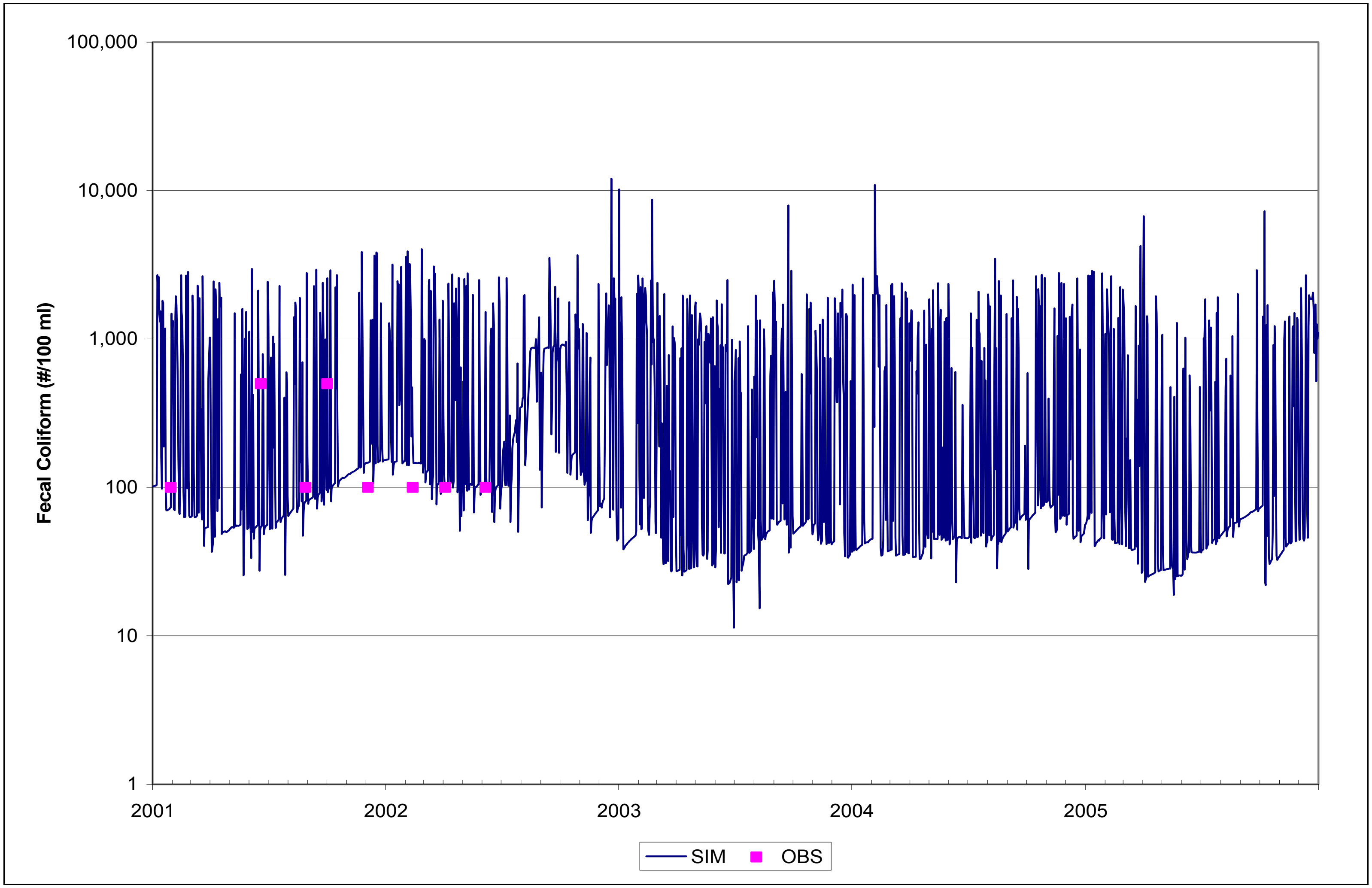


Figure 4-11: Observed and Simulated Bacteria Concentrations, Backlick Run 2001-2005

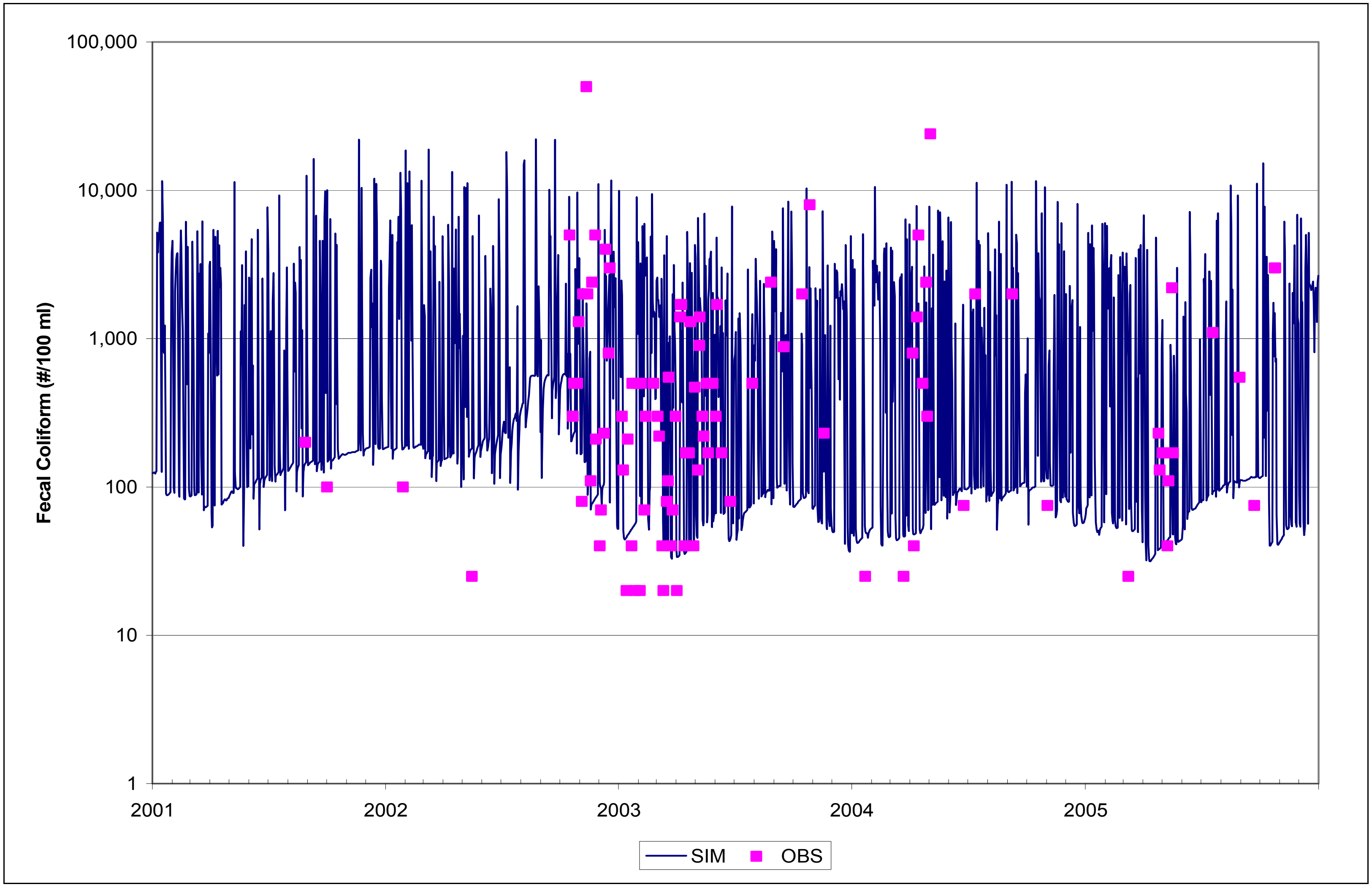


Figure 4-12: Observed and Simulated Bacteria Concentrations, Cameron Run 2001-2005

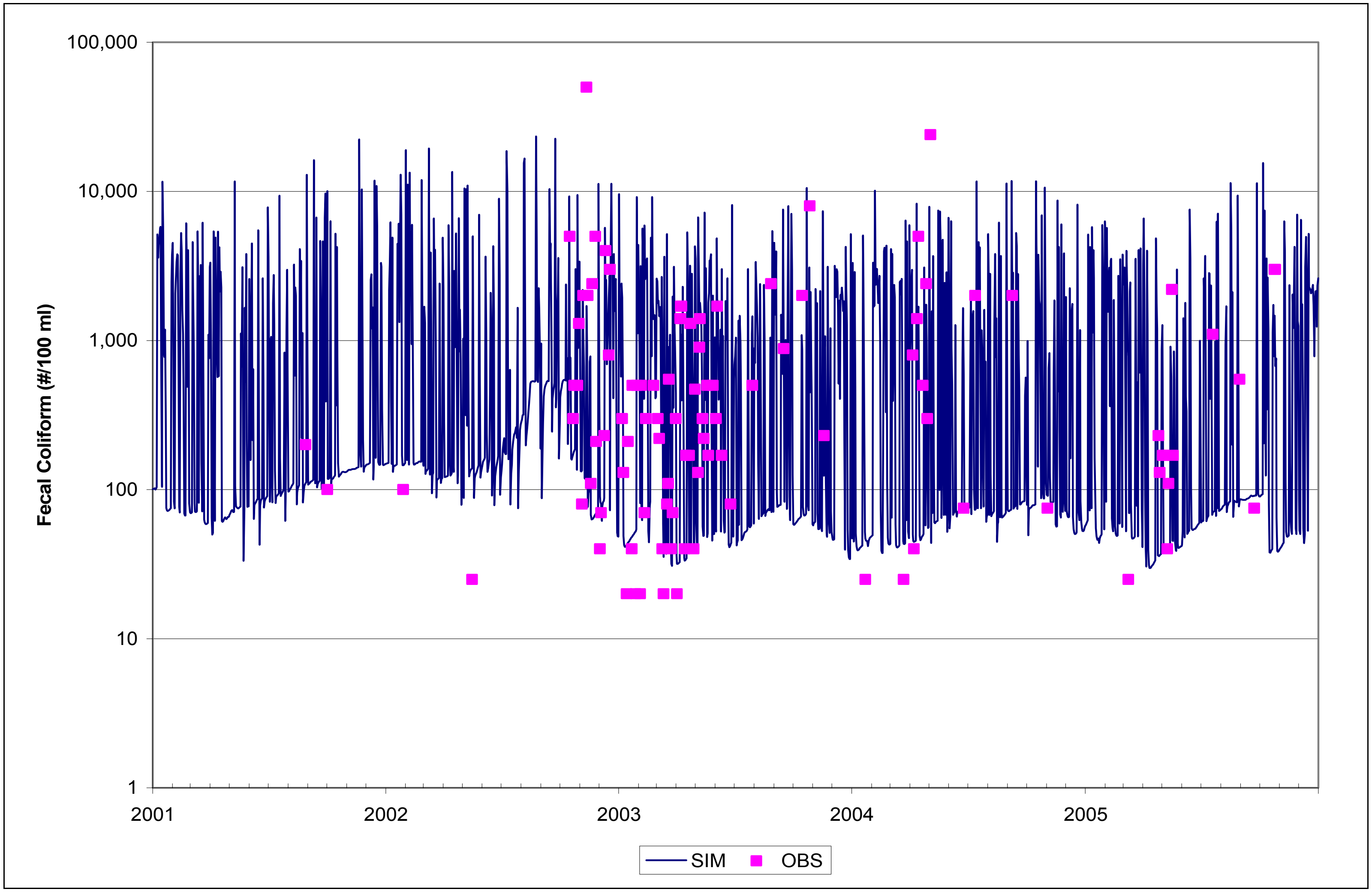


Figure 4-13: Observed and Simulated Bacteria Concentrations, Hooff Run 2001-2005

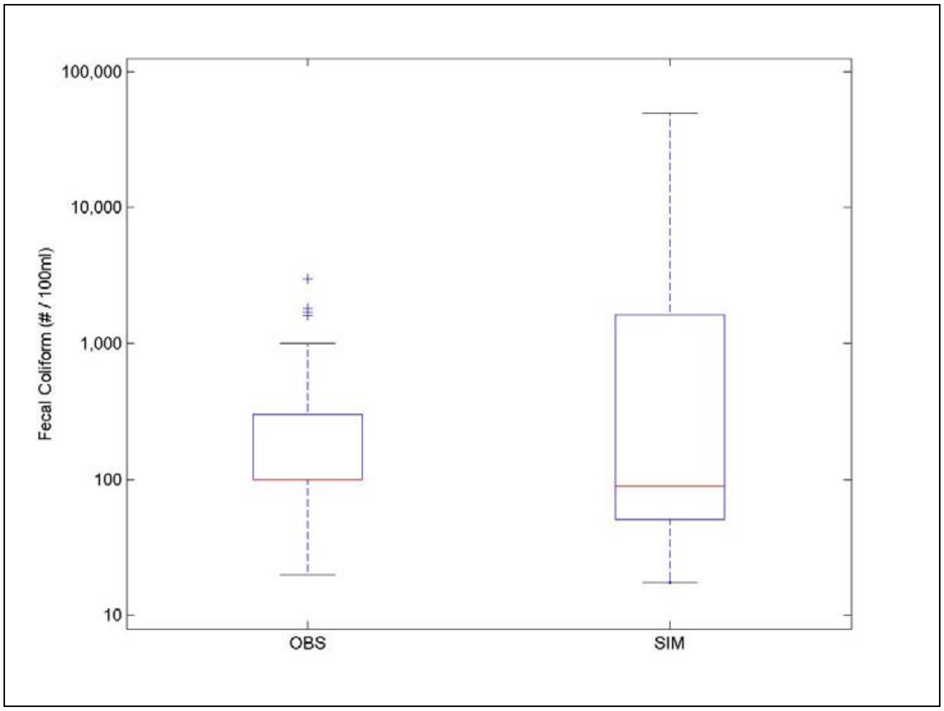


Figure 4-14: Distribution of Observed and Simulated Bacteria Concentrations, Holmes Run 2001-2005

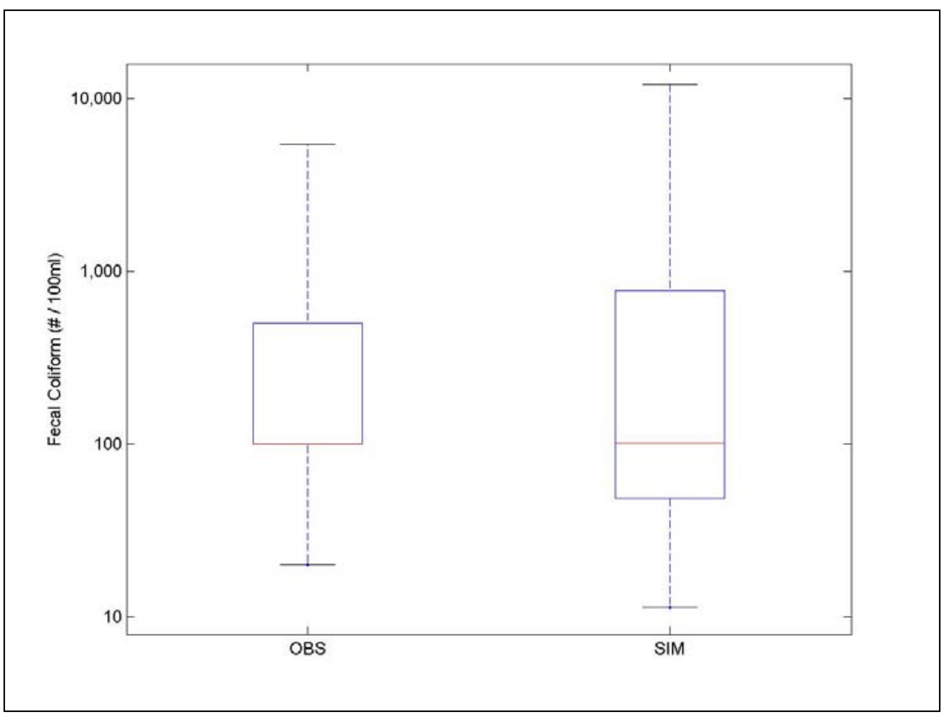


Figure 4-15: Distribution of Observed and Simulated Bacteria Concentrations, Backlick Run 2001-2005

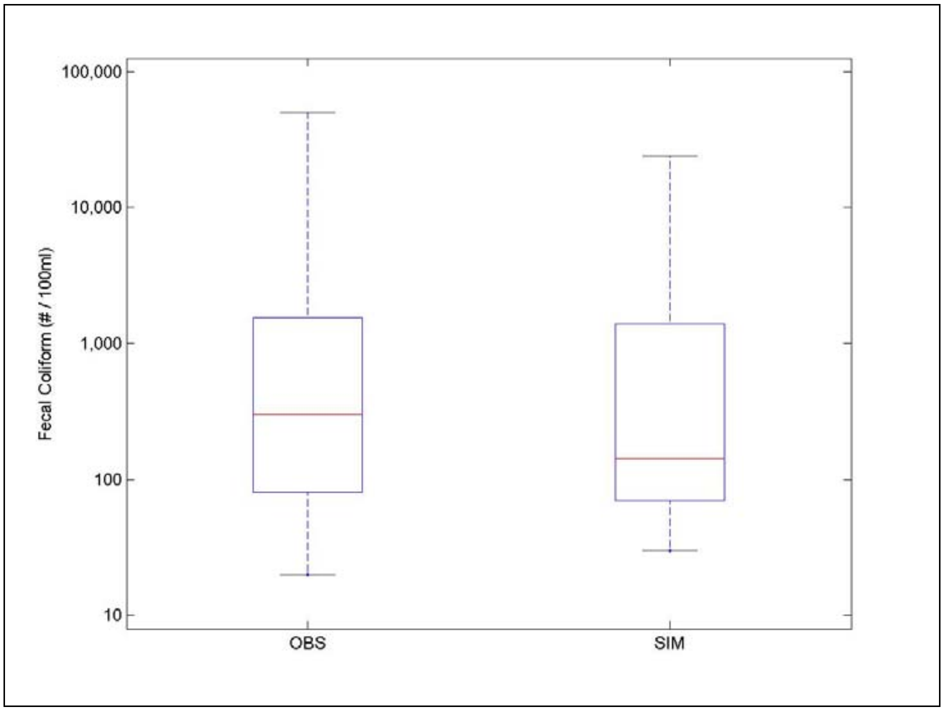


Figure 4-16: Distribution of Observed and Simulated Bacteria Concentrations, Cameron Run 2001-2005

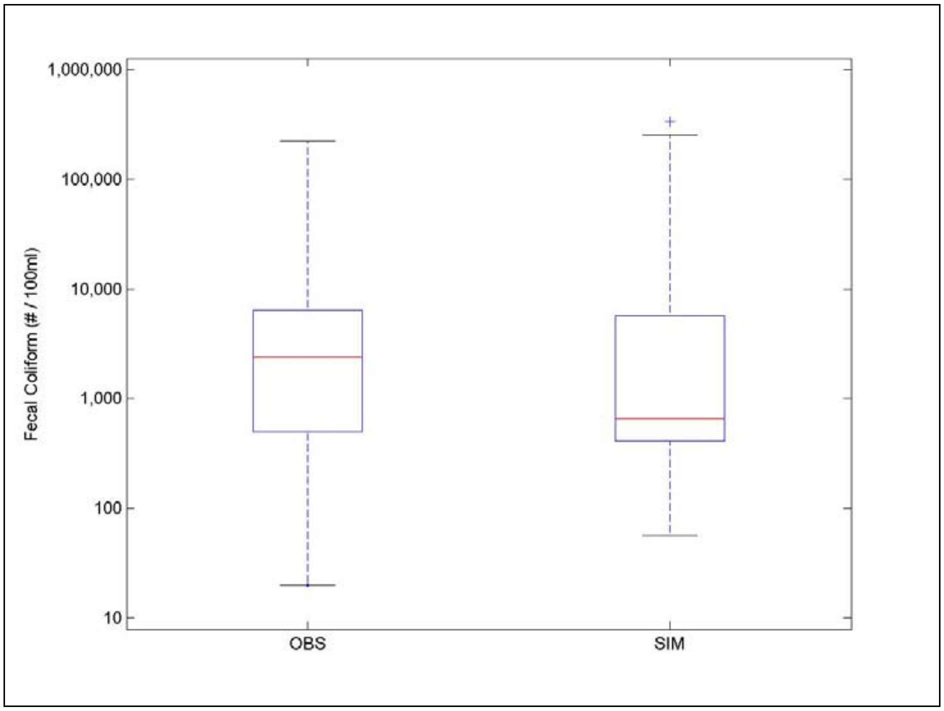


Figure 4-17: Distribution of Observed and Simulated Bacteria Concentrations, Hooff Run 2001-2005

For the verification period, goose population density was returned to their original estimated value of 2.34 per acre prior to the adoption of the population control measures described in Section 3.5.3. **Table 4-8** compares simulated geometric mean concentrations and exceedance rates with their observed targets for the verification period, 1996-2000. The performance of the simulation during the verification period is consistent with the observed data, when it is taken into account that there is no storm monitoring during the verification period.

Table 4-8: Cameron Run HSPF Model Verification Results (1996-2000)

Station	Observed		Simulated	
	Geometric Mean	Exceedance Rate	Geometric Mean	Exceedance Rate
Holmes Run	167	0.17	356	0.35
Backlick Run	246	0.28	272	0.28

4.2 Development of Input Flows and Bacteria Loads for the ELCIRC Model

Figure 4-18 shows the domain chosen to simulate the hydrodynamics as well as the fate and transport of bacteria in Hunting Creek using the ELCIRC. The domain is large enough to capture the impact of the Potomac River on Hunting Creek, but small enough to provide an accounting of the bacteria loads from sources in the Potomac River outside of the Hunting Creek drainage.

Within the Hunting Creek drainage, four sources of flows and bacteria loads can be distinguished:

- Non-tidal Cameron Run
- Direct drainage to tidal waters and smaller tributaries like Hooff Run, Quander Creek, and Strawberry Run
- ASA WWTP (VA0025160)
- Alexandria CSOs (VA0087068)

These are the sources that will be subject to load and wasteload allocations under the Hunting Creek TMDL.

In the extended domain of the ELCIRC, the following sources can be distinguished:

- Potomac River upper and lower boundaries
- The District of Columbia's Blue Plains WWTP
- Bypass flows from Blue Plains WWTP
- Direct drainage to the Potomac River from Virginia, outside of the Hunting Creek drainage (Model segments 210 and 220 – See Figure 4-18))
- Oxon Run and direct drainage to the Potomac River from the District of Columbia and Maryland (Model segments 230, 240, and 250 – See Figure 4-18)

Inputs from these sources for the calibration and verification simulations will be discussed in turn below.

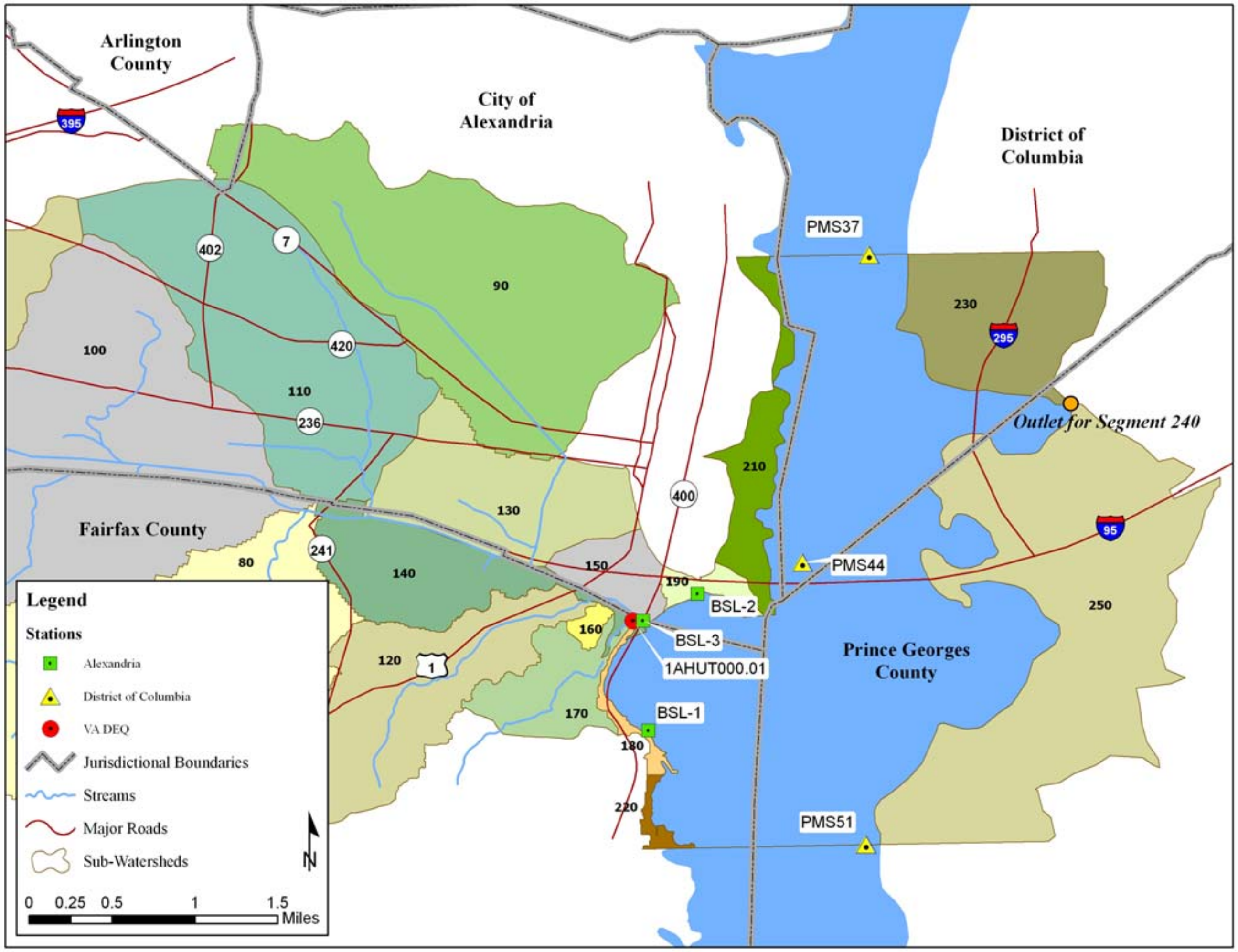


Figure 4-18: Location of Segments and Monitoring Stations in the Extended Potomac River Domain

4.2.1 Input Flows and Bacteria Loads from the Hunting Creek Drainage

Non-tidal Cameron Run

Daily average flows and bacteria concentrations for non-tidal Cameron Run were taken directly from Segment 100 of the Cameron Run HSPF model. **Table 4-9** gives the annual flow and fecal coliform bacteria load for the simulation period 2001-2005.

Direct Drainage and Small Tributaries

Daily average flows and bacteria concentrations for the direct drainage to Hunting Creek and for small tributaries entering Hunting Creek were taken directly from the corresponding segments of the Cameron Run HSPF Model. For Segments 90, 110, 120, and 170, which represent tributaries to Hunting Creek, the flows and concentrations for these segments were input into the ELCIRC model at the cells located at the confluence of the tributary with Hunting Creek. For the remaining segments, the flows and the associated concentrations were distributed along the cells adjacent to the segment. **Table 4-9** gives the annual flow and fecal coliform bacteria loads associated with these segments for the simulation period 2001-2005.

ASA WWTP

Daily flows and concentrations for the Alexandria WWTP were taken directly from the average monthly flows and concentrations provided in the discharge monitoring reports (DMR) required under its permit. Section 3.5.1 summarizes the reported flows and bacteria concentrations for this facility. **Table 4-9** gives the annual flow and fecal coliform bacteria loads associated with ASA WWTP for the simulation period 2001-2005.

Alexandria CSOs

Daily average flows for each CSO outfall, including Outfall 001 which discharges into Oronoco Bay (embayment of the Potomac River), were provided by COA from their LTCP SWMM model for the period 2001-2005. A constant fecal coliform bacteria concentration was used for each outfall and set equal to the event mean concentration for each outfall reported in Table 3.27. **Table 4-9** gives the annual flow and fecal coliform bacteria loads associated with the CSO outfalls for the simulation period 2001-2005.

Table 4-9: Annual Flows and Fecal Coliform Bacteria Loads For Sources in Hunting Creek Drainage

Source	Constituent	2001	2002	2003	2004	2005
Cameron Run (Segment 100)	Flow (cf/yr)	9.42E+08	9.59E+08	2.14E+09	1.44E+09	1.64E+09
	Bacteria (#/yr)	4.18E+14	5.58E+14	1.37E+15	6.76E+14	9.77E+14
Direct Drainage (Segment 90, 110-190)	Flow (cf/yr)	1.81E+08	1.91E+08	4.03E+08	2.71E+08	3.05E+08
	Bacteria (#/yr)	3.10E+14	4.48E+14	9.02E+14	5.77E+14	7.03E+14
ASA WWTP	Flow (cf/yr)	1.72E+09	1.64E+09	2.05E+09	2.00E+09	1.82E+09
	Bacteria (#/yr)	3.10E+13	8.39E+12	9.28E+11	1.01E+12	5.77E+11
Alexandria CSO Outfall 002	Flow (cf/yr)	5.12E+06	5.81E+06	1.36E+07	9.57E+06	1.10E+07
	Bacteria (#/yr)	4.37E+14	4.96E+14	1.16E+15	8.18E+14	9.42E+14
Alexandria CSO Outfall 003	Flow (cf/yr)	1.96E+06	2.04E+06	5.99E+06	4.48E+06	4.93E+06
	Bacteria (#/yr)	8.51E+13	8.88E+13	2.60E+14	1.95E+14	2.`14E+14
Alexandria CSO Outfall 004	Flow (cf/yr)	2.98E+05	4.29E+05	1.21E+06	9.03E+05	1.87E+06
	Bacteria (#/yr)	5.47E+13	7.88E+13	2.22E+14	1.66E+14	3.43E+14

Table 4-10 summarizes the sources of flows and bacteria concentrations for the sources receiving allocations under the Hunting Creek/Cameron Run TMDL.

Table 4-10: Summary of Sources of Bacteria Loads in Hunting Creek Drainage

Source	Flow	Bacteria
Cameron Run	HSPF	HSPF
Direct Drainage	HSPF	HSPF
ASA WWTP	DMR	DMR
CSOs	LTCP SWMM	Monitoring Data EMCs

4.2.2 Baseline *E. coli* Loads

The HSPF Cameron Run model and the bacteria inputs from ASA WWTP and COA CSOs are simulated in terms of fecal coliform bacteria. Bacteria TMDLs for Holmes Run, Cameron Run, and Hunting Creek, as well as the load and wasteload allocations, must be expressed in

E. coli bacteria. Edge-of-stream (EOS) *E. coli* loads from the Cameron Run HSPF model by land use and segment were obtained from simulated fecal coliform model output as follows:

1. For each segment, daily fecal coliform concentration was calculated from the total flow and daily fecal coliform load, i.e. the daily sum of the flows and loads from all land uses in a segment, in addition to upstream loads if applicable.
2. The fraction of the total daily fecal coliform load from each land use and segment was calculated on a daily basis.
3. The daily fecal coliform concentration in (1) was converted to an *E. coli* concentration using the VADEQ translator equation.
4. The daily *E. coli* concentration was converted to a daily load by multiplying by the total daily flow.
5. The total daily *E. coli* load was partitioned among the land uses in a segment in proportion to their share of the total fecal coliform load calculated in (2).

Average annual *E. coli* loads by land use and segment are given in Table A.5 in Appendix A.

4.2.3 Input Flows and Bacteria Loads from the Extended Potomac River Domain

Potomac River Boundaries

Tidal elevations and flows across the upper and lower Potomac River boundaries were taken from the ELCIRC model simulation of the original domain.

The upper and lower boundaries of the extended Potomac River domain were set at the location of the District of Columbia's Department of the Environmental (DC DOE) monitoring stations PMS37 and PMS51, respectively. The locations of these monitoring stations are shown in Figure 4-18. Bacteria data were generally collected monthly during the 2001-2005 simulation period. **Table 4-11** summarizes the observed concentrations at these locations and at PMS44, also shown in Figure 4-18, which was used to help calibrate the model.

Table 4-11: Summary Statistics for Fecal Coliform Concentrations (cfu/ 100 ml) at DC DOE Monitoring Stations in Vicinity of Hunting Creek, 2001-2005

Statistic	PMS37	PMS44	PMS51
Minimum	20	20	20
1st Quartile	40	40	20
Median	90	120	110
3rd Quartile	300	300	265
Maximum	5,000	3,000	13,000
Average	343	327	558
Standard Deviation	753	557	1,915

Blue Plains WWTP

Daily flows and concentrations for the Blue Plains WWTP were taken directly from the average monthly flows and concentrations provided by the Washington Water and Sewer Authority (DC WASA). **Table 4-12** summarizes the reported flows and bacteria concentrations. **Table 4-13** gives the annual flow and fecal coliform bacteria loads associated with Blue Plains WWTP for the simulation period 2001-2005.

Table 4-12: Summary Statistics for Average Monthly Flow (MGD) and Fecal Coliform Bacteria Concentration (cfu/100 ml) for Blue Plains WWTP, 2001-2005		
Statistic	**Flow**	**Concentration**
Minimum	282	1.0
1st Quartile	312	2.3
Median	331	4.4
3rd Quartile	351	9.4
Maximum	425	53.0
Average	332	7.8
Standard Deviation	30	9.1

Table 4-13: Annual Flows and Fecal Coliform Bacteria Loads For Sources in Extended Potomac Domain						
Source	**Constituent**	**2001**	**2002**	**2003**	**2004**	**2005**
Oxon Run (Segment 230)	Flow (cf/yr)	2.72E+07	2.49E+07	6.41E+07	3.31E+07	4.00E+07
	Bacteria (#/yr)	1.06E+14	1.08E+14	2.17E+14	1.18E+14	1.51E+14
VA Direct Drainage (Segments 210, 220)	Flow (cf/yr)	9.96E+06	1.07E+07	2.19E+07	1.47E+07	1.65E+07
	Bacteria (#/yr)	1.14E+13	1.68E+13	3.34E+13	2.21E+13	2.68E+13
MD,DC Direct Drainage (Segments 230, 250)	Flow (cf/yr)	5.00E+08	4.30E+08	1.32E+09	6.44E+08	7.75E+08
	Bacteria (#/yr)	1.55E+15	1.57E+15	3.36E+15	1.75E+15	2.32E+15
Blue Plains WWTP	Flow (cf/yr)	1.55E+10	1.52E+10	1.82E+10	1.64E+10	1.58E+10
	Bacteria (#/yr)	2.34E+13	3.06E+13	4.52E+13	3.64E+13	1.83E+13
Blue Plains Bypass	Flow (cf/yr)	2.08E+07	7.46E+07	3.18E+08	1.11E+08	1.56E+08
	Bacteria (#/yr)	5.04E+14	1.94E+15	1.18E+16	1.00E+16	1.50E+16
Alexandria CSO Outfall 001	Flow (cf/yr)	2.06E+06	1.89E+06	7.26E+06	5.44E+06	6.62E+06
	Bacteria (#/yr)	2.86E+14	2.62E+14	1.01E+15	7.57E+14	9.20E+14

<u>Blue Plains Bypass</u>

The District of Columbia has a combined sewer system (CSS) covering 12,478 acres. During storm events, if the flows exceed the treatment and storage capacity of the sanitary sewer conveyance system or the Blue Plains treatment facility, they are discharged to the Potomac or Anacostia Rivers. Outfall 0001 at Blue Plains is a location where untreated or partially treated sewage is discharged into the Potomac when the capacity of Blue Plains is exceeded. DC WASA provided flows and observed concentrations on an event basis at Outfall 001. **Table 4-14** summarizes the flows and bacteria concentrations observed during the 2001-2005 simulation period. Table 4-13 gives the annual flow and fecal coliform bacteria loads associated with Blue Plains bypasses for the simulation period of 2001-2005.

Table 4-14: Summary Statistics for Average Flow (MGD) and Fecal Coliform Bacteria Concentration (cfu/100 ml) for Blue Plains Bypass, 2001-2005

Statistic	Flow	Concentration	Events per Year
Minimum	0.80	36	8
1st Quartile	9.28	3,650	20
Median	22.74	30,500	22
3rd Quartile	50.68	247,500	23
Maximum	212.44	1,560,000	46
Average	38.56	167,685	24
Standard Deviation	41.47	289,194	12

<u>Virginia Direct Drainage in the Extended Potomac Domain</u>

Segments 210 and 220, shown in Figure 4-18, represent portions of Virginia draining to the extended Potomac River domain outside the drainage area of the Hunting Creek drainage. Segment 210 is primarily in Old Town Alexandria. Segment 220 is primarily land associated with the George Washington Memorial Parkway. A portion of Dyke's Marsh occupies some of segment 220.

Segments 210 and 220 were simulated in the Cameron Run HSPF model. Land use for these segments was estimated using the methods described in Sections 3.2.3 and 4.1.3. **Table 4-15** gives the land use acreage for each segment. They were simulated using parameters taken from adjoining segments: Segment 130 for Segment 210 and Segment 180 for Segment 220. Table 4-13 gives the annual flow and fecal coliform bacteria loads associated with Segments 210 and 220 for the simulation period 2001-2005.

Table 4-15: Model Land Use for VA Direct Drainage Segments to Extended Potomac Domain				
Land Use	**Segment 210**		**Segment 220**	
	Pervious (acres)	**Impervious (acres)**	**Pervious (acres)**	**Impervious (acres)**
Open Space	43.42	7.13	20.97	0.0
Transportation	13.65	6.52	0.0	0.0
Low Density Residential	0.0	0.0	0.0	0.0
Medium Density Residential	0.0	0.0	0.0	0.0
High Density Residential	19.79	29.60	0.0	0.0
Commercial	18.78	44.64	0.0	0.0
Industrial	0.0	0.0	0.0	0.0

Direct Drainage in Maryland and the District of Columbia in the Extended Potomac Domain

Segment 240 represents Oxon Run, a tributary to the Potomac River flowing through both Maryland and the District of Columbia. Segment 230 represents the portion of the District which drains to the extended Potomac domain outside of Oxon Run, and Segment 250 represents the portion of Maryland which drains to the extended Potomac domain outside of Oxon Run. The location of these segments is shown in Figure 4-18.

Land use for these areas was taken from the Chesapeake Bay Program's Phase 5.2 Watershed Model (P52). P52 is an HSPF model of the entire Chesapeake Bay drainage, used to estimate flows, and constituent loads into the Bay. **Table 4-16** gives the land use for each segment. Simulated daily flows were also taken from the model. Flows were divided into stormflow and baseflow based on the HSPF simulation. Fecal coliform bacteria concentrations were assigned to stormflow and baseflow as shown in **Table 4-17**. Bacteria concentrations for the District and Oxon Run were taken from the DC Small Tributaries Model which was used to develop TMDLs for smaller streams in the District of Columbia. A bacteria TMDL for Oxon Run was developed using this model. The bacteria concentrations used for Maryland were taken from MS4 monitoring data for Prince George's County. Table 4-13 gives the annual flow and fecal coliform bacteria loads associated with Segments 230, 240 and 250 for the simulation period 2001-2005.

Table 4-16: Model Land Use for DC and MD Direct Drainage Segments to Extended Potomac Domain

Segment	Pervious	Impervious
230 (DC)	233	207
240 (Oxon Run)	5,750	2,948
250 (MD)	1,222	142

Table 4-17: Input Fecal Coliform Concentrations (cfu/100 ml) for MD and DC Direct Drainage Segments to Extended Potomac Domain

Segment	Baseflow	Stormflow
230 (DC)	280	17,300
240 (Oxon Run)	280	17,300
250 (MD)	671	2,895

Tidal Elevation at Potomac River Boundaries

The ELCIRC model also requires that the tidal elevation at the boundaries of the extended domain be specified. Tidal elevations at these boundaries were calculated using astronomical tide with harmonic components of M2, S2, N2, O1, and K1 generated by WXTide32 tidal prediction software (http://wxtide32.com). WXTide32 is a Windows version of XTide, which calculates astronomical tides from tidal harmonics using the same algorithms as NOAA's National Oceanic Service (Flater, 2005).

Tidal elevation data from the station Bellevue (77^0 02.00W, 38^0 50.00 N) and at the station Riverview Maryland (77^0 09.00W, 38^0 23.00 N) were assigned at the northern boundary and the southern boundary conditions, respectively.

Summary of Sources of Flows and Bacteria Loads in the Extended Potomac Domain

Table 4-18 summarizes the sources of flows and bacteria concentrations for the sources in the Extended Potomac domain for the ELCIRC model.

Table 4-18: Summary of Sources of Flows and Bacteria Loads in Extended Potomac Domain		
Source	**Flow**	**Bacteria**
VA Direct Drainage	HSPF	HSPF
MD and DC Direct Drainage (including Oxon Run)	CBP P52 Model	MS4 monitoring data
Blue Plains WWTP	DMR	DMR
Blue Plains Bypass	DC WASA	DC WASA
Potomac Boundary	WXTide32[1]	DC DOE Monitoring Data

[1] *The Potomac River boundary requires tidal elevations, rather than flows, as a boundary condition.*

4.3 The ELCIRC Model of Tidal Cameron Run, Hunting Creek, and the Adjacent Potomac River

Fecal coliform bacteria in tidal Hunting Creek was simulated using the ELCIRC hydrodynamic and fecal coliform water quality model (Zhang et al. 2004; Wang et al.2008). This section discusses the development and calibration of the ELCIRC model of Hunting Creek and the extended Potomac River domain. After a brief overview of ELCIRC (Section 4.3.1), the model domain (Section 4.3.2), simulation period (Section 4.3.3), and model bathymetry and grid (Section 4.3.4) are discussed. Sections on the hydrodynamic calibration (Section 4.3.4) and the bacteria calibration (Section 4.3.5) follow the discussion of the set-up of the model.

4.3.1 Overview of the ELCIRC Model

The ELCIRC hydrodynamic model solves shallow water equations using a semi-implicit, semi-Lagrangian (also known as Eulerian–Lagrangian) finite volume/finite difference method reliant on horizontally unstructured grids and un-stretched z-coordinates. ELCIRC use of turbulence closure schemes (Umlauf and Burchard, 2003), includes terms for the tidal potential and atmospheric pressure gradients, and provides an air–water exchange term such as forcing by wind stress. Its special features include:

1. Semi-implicit scheme. A semi-implicit scheme means (a) the barotropic pressure gradient in the momentum equation and the flux term in the continuity equation are treated semi-implicitly, with implicitness factor 0:5; (b) the vertical viscosity term and the bottom boundary condition for the momentum equations are treated fully implicitly; and (c) all other terms are treated explicitly. This ensures both stability and computational efficiency (Casulli and Cattani, 1994).

2. The normal component of the horizontal momentum equation is solved simultaneously with the depth-integrated continuity equation, i.e., there is no mode splitting between these equations. The total derivatives of the normal velocity are discretized using Lagrangian backtracking, thus preventing advection from imposing stability constraints on the time step.

3. The tangential component of the horizontal momentum equation is formally solved with finite differences. The solution is computationally efficient, because matrices formed and inverted in the process of computing normal velocities are reused. The vertical velocity is solved from the 3-D continuity equation using a finite volume approach.

4. The numerical algorithms are volume conservative, stable and naturally incorporate a robust handling of wetting and drying of tidal flats. If a two-and-a-half equation turbulence closure is invoked, the eddy viscosity and diffusivity are computed at each time step prior to the solution.

Mass Conservation

Mass conservation is critical element in coupling a fecal coliform water quality model to a hydrodynamic model. Without the conservation of mass both globally and locally, small errors introduced by large magnitude physical transport can easily, if not completely, obscure the accuracy of smaller magnitude biogeochemical processes.

Wang *et al*. (2008) found that is necessary to modify the original transport scheme in ELCIRC to accurately satisfy mass conservation. They replaced the original Euler-Lagrangian scheme with a finite-volume/finite difference upwind scheme derived from the CE-QUAL-ICM model (Cerco and Cole, 1995). Wang *et al*. subjected both the original ELCIRC formulation and the revised scheme to three tests: (1) a local mass conservation test; (2) a global mass conservation test for conservative and nonconservative substances; and (3) a wetting-and-drying scheme test. In all three tests, the revised scheme outperformed the original scheme, demonstrating conservation of mass both locally and globally with minimum error[1].

---

[1] A finite-volume algorithm for solving the scalar transport equation on orthogonal unstructured grids was also derived by Casulli and Zanolli (1998, 2005). Their computed results also showed that the algorithm not only conserves mass locally and globally but also satisfies a discrete maximum principle.

The revised scheme was incorporated into ELCIRC for the simulation of bacteria in tidal Hunting Creek and adjacent sections of the Potomac River. This version of the ELCIRC model with the conservation scheme has been subject to additional tests of mass conservation by comparing simulated results with semi-analytic solution of the advection-dispersion equation for a substance with first order decay (Loftis and Wang, 2010.)

4.3.2 Model Domain and Grid of the Hunting Creek ELCIRC Model

The ELCIRC model domain covers tidal Hunting Creek, from Telegraph Road, downstream past the George Washington Memorial Parkway Bridge (G.W. Parkway) and throughout the embayment. It also includes a section of the Potomac River from Belle Haven/New Alexandria (in the south) to Bellevue (in the north), as shown in Figure 4-19. Tidal Hooff Run, which serves as a conduit for CSO outfalls 003 and 004, is represented as a one-dimensional channel branching from the Duke Street bridge crossing (where Hooff Run is day-lighted) to its confluence with Hunting Creek. Also included is Oronoco Bay, a small embayment of the Potomac River into which CSO Outfall 001 discharges. Hereafter, the model will be called the Hunting Creek ELCIRC Model.

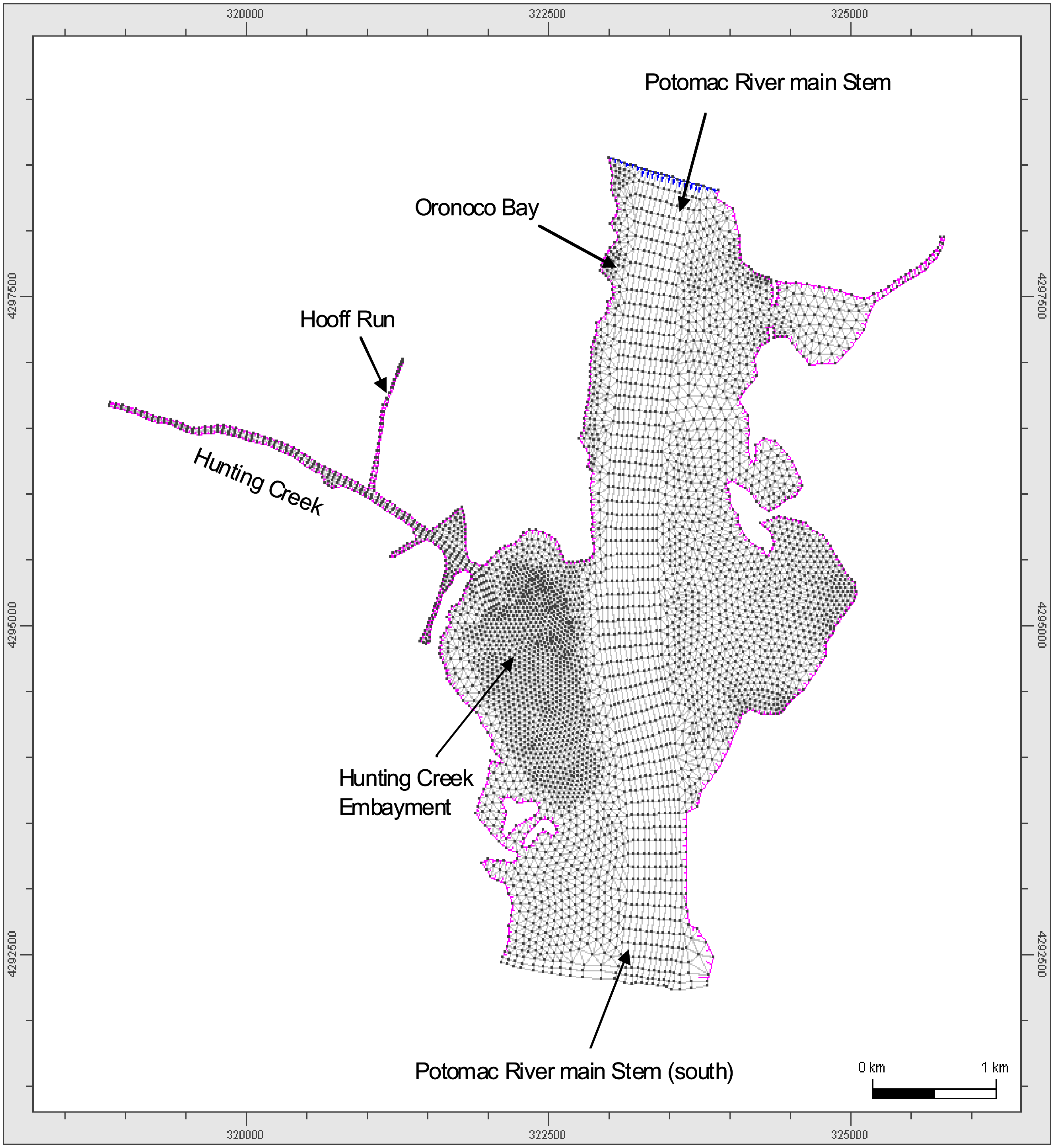


Figure 4-19: The Model Domain and Grid of Hunting Creek ELCIRC Model

4.3.3 Calibration and Verification Periods

The model calibration period selected for the ELCIRC model was 2001-2003 and the verification period was 2004-2005. 2003 is the year with the largest number of fecal coliform bacteria samples in the tidal waters of Hunting Creek. COA began collecting data at three locations in tidal Hunting Creek as part of their CSS permit in late 2002. VADEQ's main monitoring station for tidal Hunting Creek is Station 1AHUT000.01, located at the G. W. Parkway. VA DEQ has monitored this station for a number of years, including the majority of years used in the ELCIRC model calibration and verification periods (2001 and 2003 – 2005). Section 3.4 summarizes the data available at locations in Hunting Creek.

To start the model, the initial condition is required in January 2001. Given no initial spatial distribution of hydrodynamic water level and fecal coliform concentration in January 2001, the model was spun up from no motion and zero concentration with a time varying hydrodynamic boundary condition and fecal coliform daily load. The January condition was repeated for 6 months cyclically until it reached an equilibrium state. The final result of the equilibrium state was then used as the initial condition for the actual simulation for the year of 2001. For the latter years: 2002, 3003, 2004 and 2005, the end result in December of the previous year was saved and used in turn as the initial condition for January in the following year.

4.3.4 ELCIRC Model Shoreline and Bathymetry

The shoreline and bathymetry are system inputs to the model. The shoreline data EC80_03 is obtained from the NOAA coastal geospatial website:
http://coastalgeospatial.noaa.gov/gis_files/shoreline/ec80_03_charts_used.html.

The baseline bathymetry data for the entire model domain was taken from a NOAA gridded relief model with 90 meter resolution (National Geophysical Data Center, 2002). This information was supplemented in Hunting Creek by data provided by VADEQ and Virginia Department of Transportation (VDOT) as part of Woodrow Wilson Bridge replacement project (HNTB, 2000).

The shoreline and bathymetry data were interpolated onto the model grid to form the geometric representation of Hunting Creek and Potomac River. The depth of the Potomac River and Hunting Creek in this area ranges from 0.3 meters in the shallow inter-tidal zone to 10 meters in the deep channel of the Potomac River mainstem. A color coded image of the model grid and the topography is shown in Figure 4-20.

The grid generated for the Hunting Creek ELCIRC Model contains both three- and four-sided polygons. There 14,120 grid cells and 4,550 nodes representing the vertices of the cells. The resolution of the grid is approximately 50-90 meters in the horizontal direction and 30-50 meters in the longitudinal direction. The time step for ELCIRC running on this grid is three minutes.

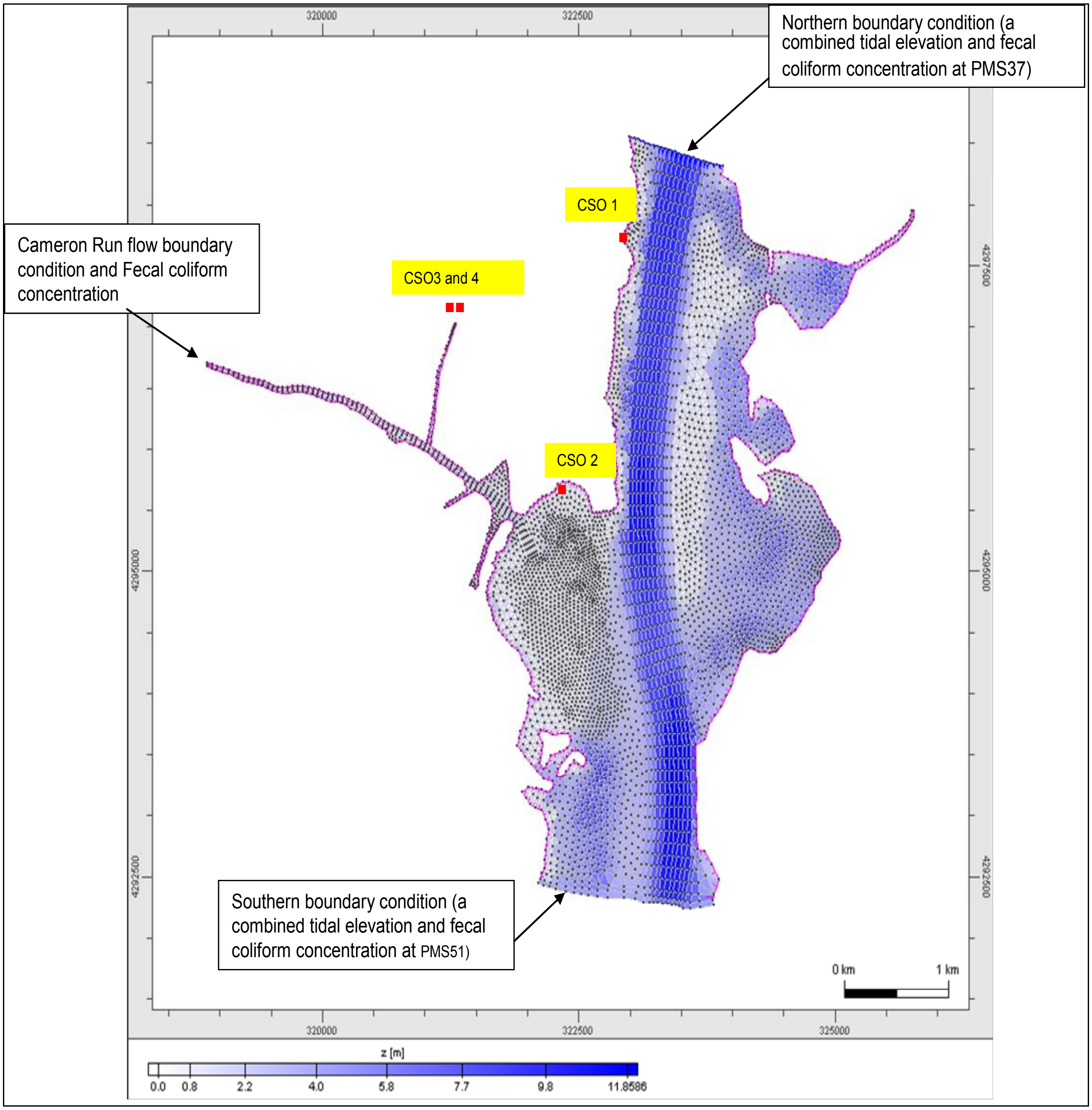


Figure 4-20: Hunting Creek and the adjacent Potomac River model grid with the associated topography and the location of boundary conditions

4,3,5 Hydrodynamic Calibration

In the numerical modeling context, calibration is defined as the process of adjusting model parameters so that the model outputs agree within a specified accuracy with the observation data. Validation is the process to confirm that the model indeed meets the specified accuracy as compared to an independent dataset without changing the calibrated parameters.

The goal of the hydrodynamic calibration is to accurately simulate observed water surface elevations. Surface water elevations measured by USGS from July 1 to July 31, 2004 at Station 0165258890 on the Potomac River at the Cameron Street Dock in Alexandria were used to calibrate the model. The Chezy coefficient is the major parameter used to calibrate the hydrodynamic model. In shallow, tidal hydraulics, the flow resistance is often expressed as the bottom shear stress using the Chezy formulation as:

$$\tau_{bottom\ shear\ stress} = \rho \mathrm{g} \frac{u^2}{{c_{chezy}}^2}$$

where ρ is the density, g is the gravity, u is the vertically averaged velocity, and c_{chezy} is the Chezy coefficient. The Chezy coefficient ranges typically from 30 $m^{1/2}$/sec (small rough channel) up to 90 $m^{1/2}$/sec (large smooth channel).

Since the observed data for this hydrodynamic calibration is real-time water level data that contains water level variability induced by tides, wind and river flows, a Chesapeake Bay, bay-wide 3D model developed by Cho Kyoung (2009) was adopted to generate tidal elevations at the open boundaries of the Potomac River during the period from July 1 to July 31, 2004. The hourly real-time water level from July 1-31, 2004 was produced by a Chesapeake Bay-wide 3D hydrodynamic model, which was forced by eight tidal constituents: M_2, S_2, N_2, O_1, K_1, Q_1, P_1, and K_2, climatologic salinity data at the continental shelf boundary, eight major river discharges including that of Potomac River, and the wind field from 13 observation stations. Figure 4-21 shows the bay-wide Chesapeake Bay model domain.

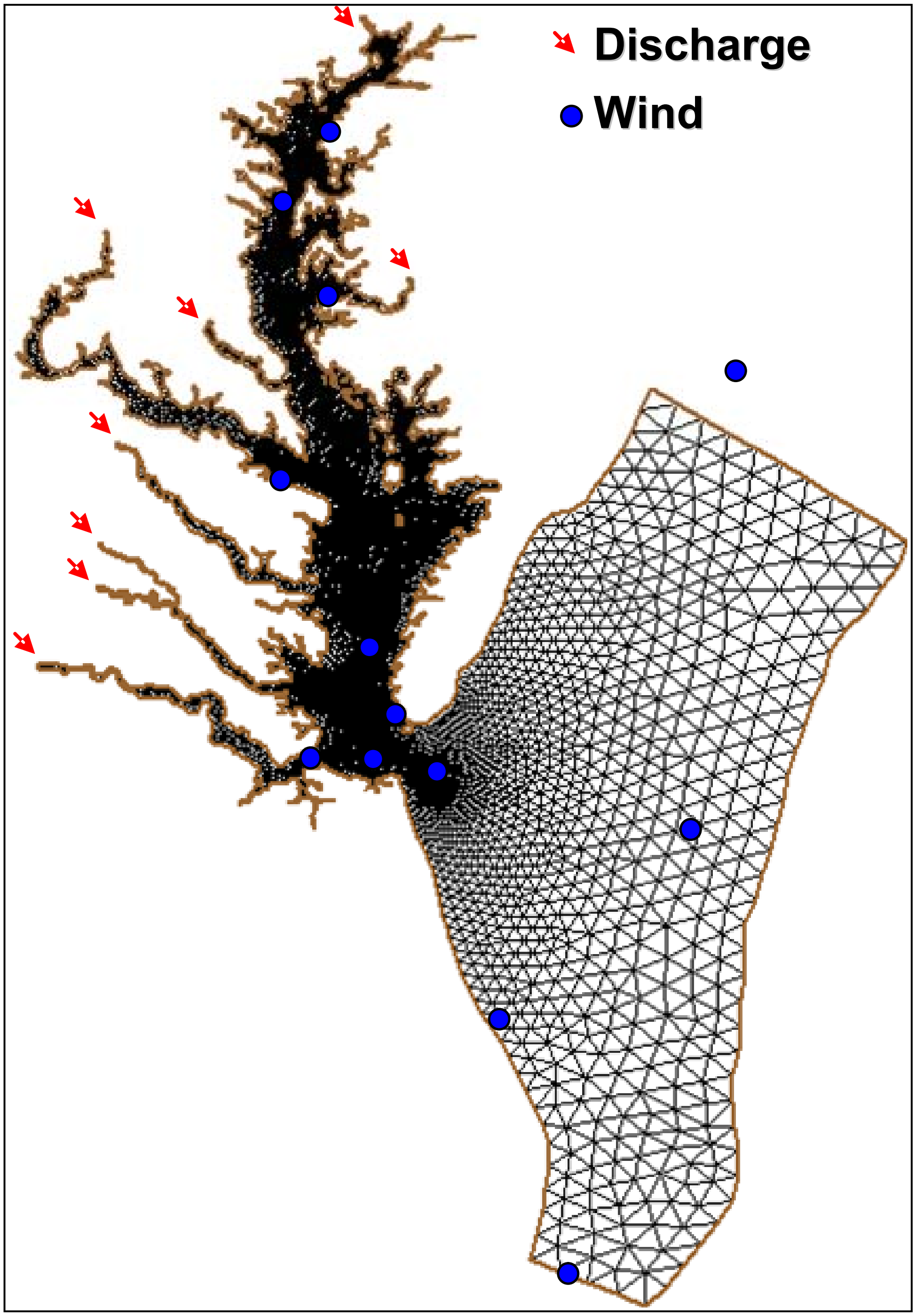


Figure 4-21: The Chesapeake Bay, bay-wide model domain and the inputs of forcings (Cho, Kyoung-Ho, 2009)

The simulated real time water level from the bay-wide model was saved at the northern and southern boundary conditions and used to drive the Hunting Creek model. The boundary conditions in the north and south in turn drive the Hunting Creek and Potomac River hydrodynamic model. Initially, a Chezy coefficient of 30- 60 $m^{1/2}$/sec was used. The results of using this Chezy coefficient showed that the model-produced wave level was underestimated as compared with the observation. Next, Chezy coefficients ranging from 60 $m^{1/2}$/sec to 90 $m^{1/2}$/sec were tested in an iterative process. In the end, it was found that the value of 70 $m^{1/2}$/sec was most appropriate in generating the best-fit of water level. An example of water level using a Chezy coefficient of 60 $m^{1/2}$/sec versus 70 $m^{1/2}$/sec during July 1 – 22 period are shown in **Figures 4-22** and **4-23**, respectively. The comparison demonstrates that as the Chezy coefficient is increased to 70 $m^{1/2}$/sec. the bottom shear is reduced, which gives better results when compared to the observed real-time water level than those provided by the 60 $m^{1/2}$/sec. coefficient.

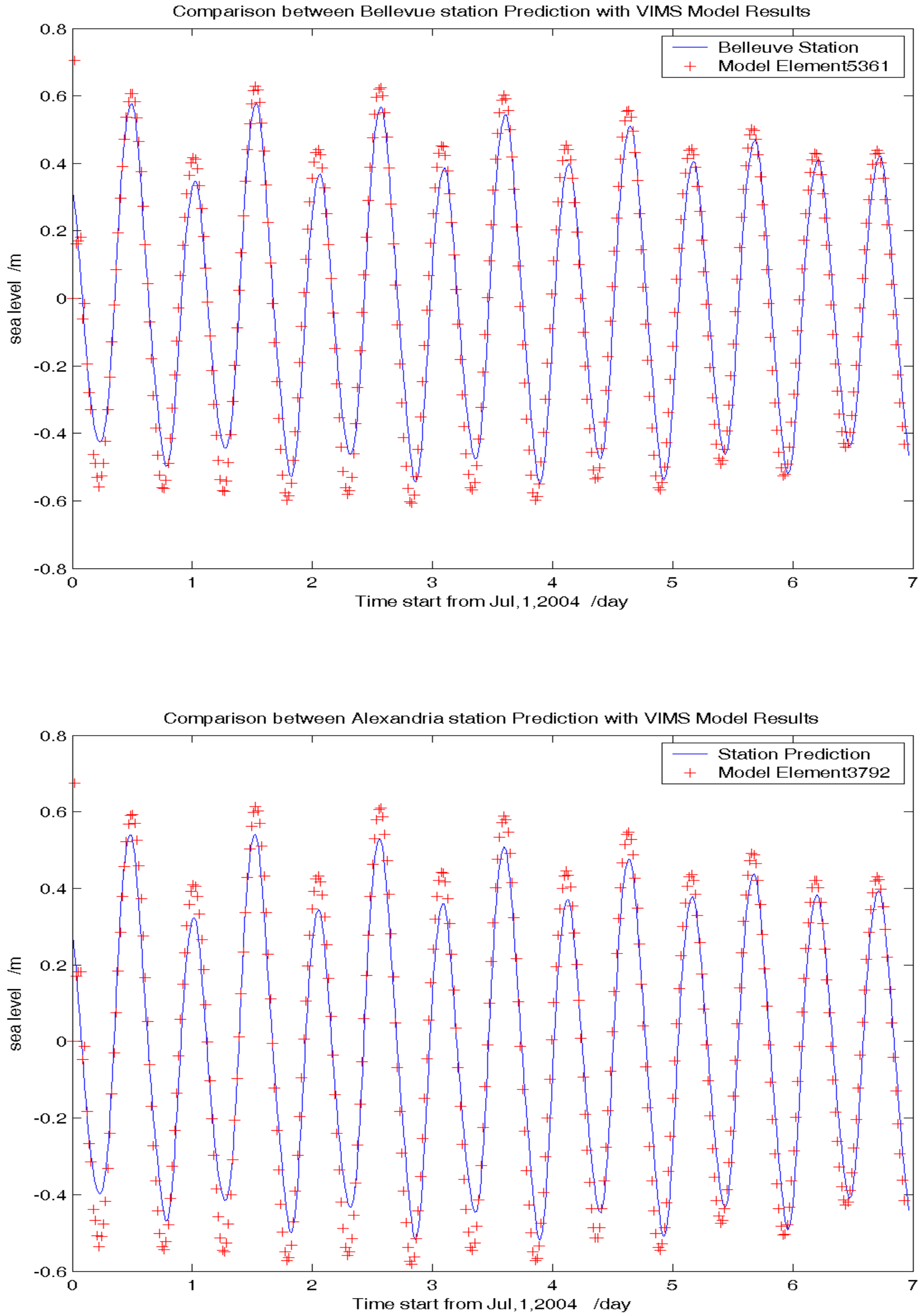
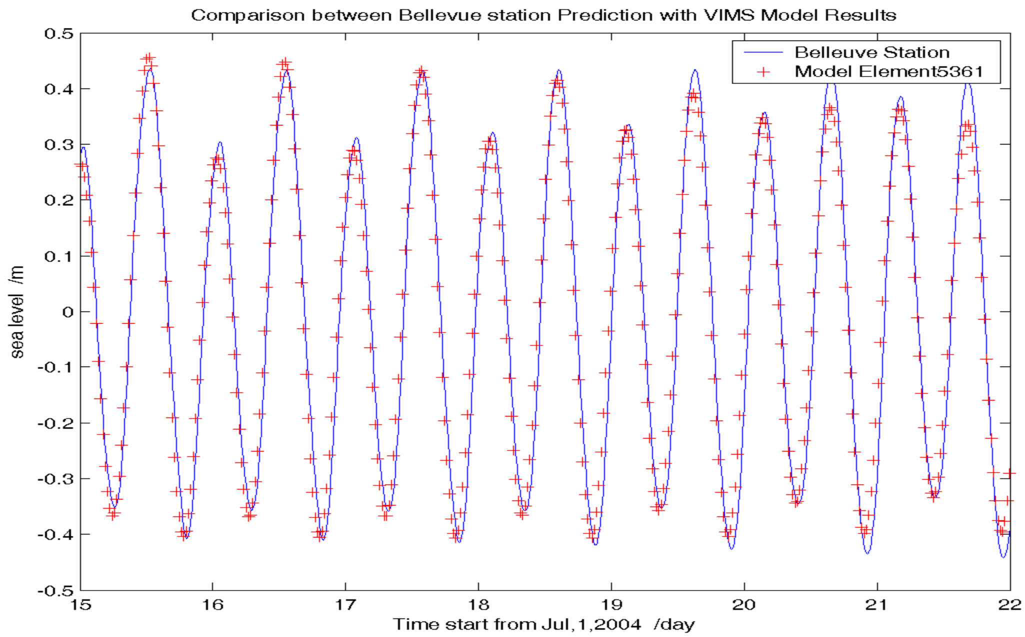


Figure 4-22: Time series comparison of observed and modeled water level, July 1-22, 2004 (Chezy coefficient of 60 m1/2/sec)



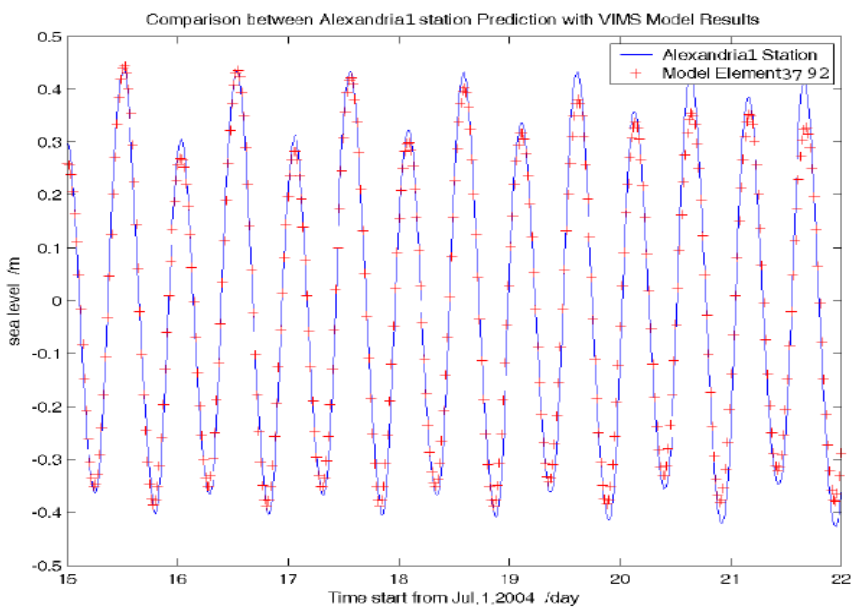


Figure 4-23: Time series comparison of observed and modeled water level, July 1-22, 2004 (Chezy coefficient of 70 m1/2/sec)

The hydrodynamic calibration was verified by comparing simulated water elevations to independent synthetic time series of water elevations generated by WXtide32 at the four locations shown below in Figure 4-24: Bellevue (38.8267, -77.0267), Bellevue2 (38.8333, -77.0333), Alexandria (38.805, -77.0383), and Alexandria 2 (38.800, -77.0333). **Figure 4-24** shows these locations.

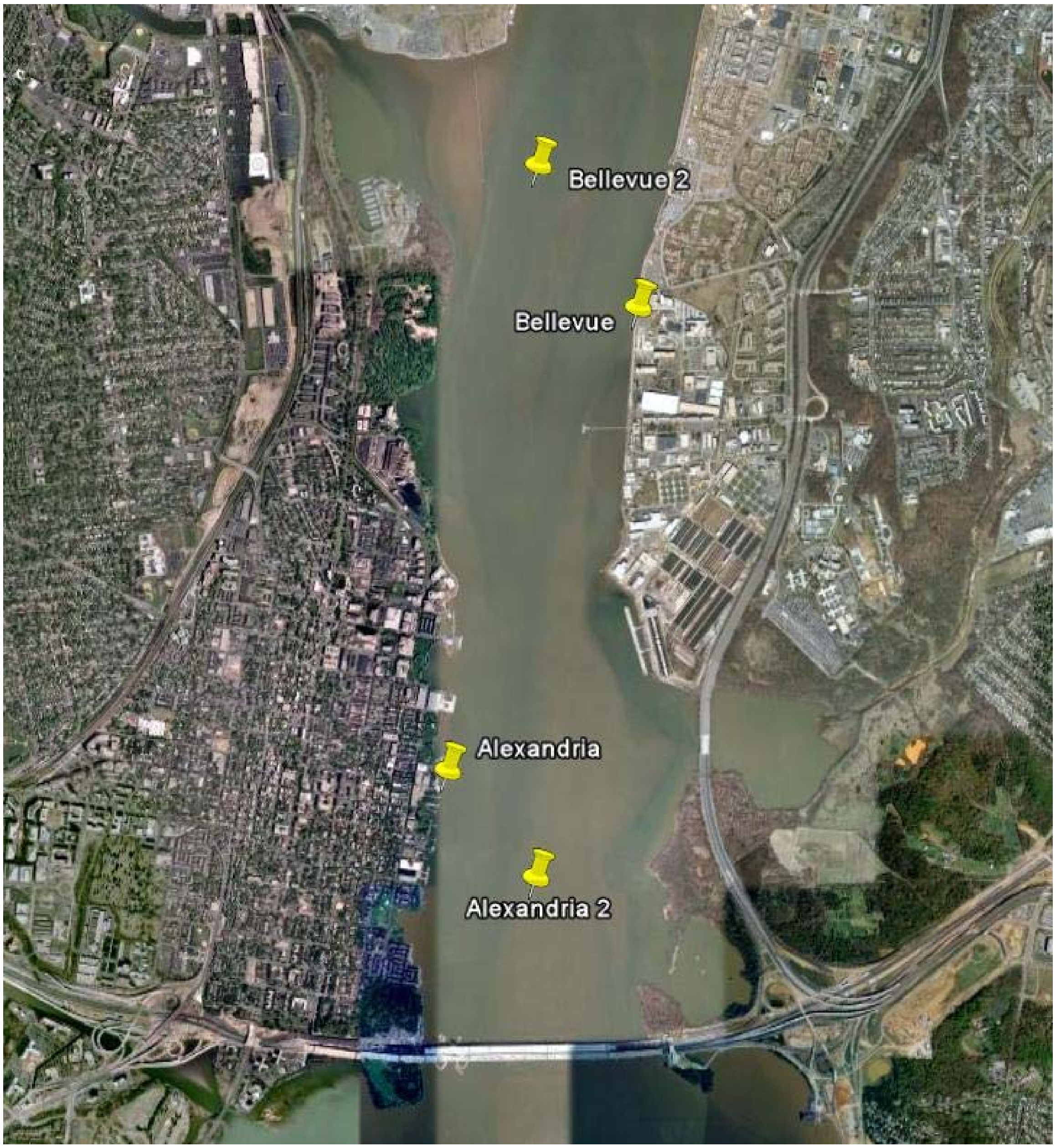


Figure 4-24: Synthetic Tide Locations Used to Verify ELCIRC Hydrodynamic Simulation

For verification, the tidal elevations at the open Potomac River boundaries were set at Bellevue and at Riverview, Maryland using synthetic tide data generated by WXTide32, as described in Section 4.2. **Figures 4-25, 4-26**, and **4-27**, respectively show the model output elevation compared with the tidal data at Bellevue2, Alexandria and Alexandria2 for the entire month of July 2004. It confirmed that the model indeed produced accurate results without changing the previous calibrated parameters.

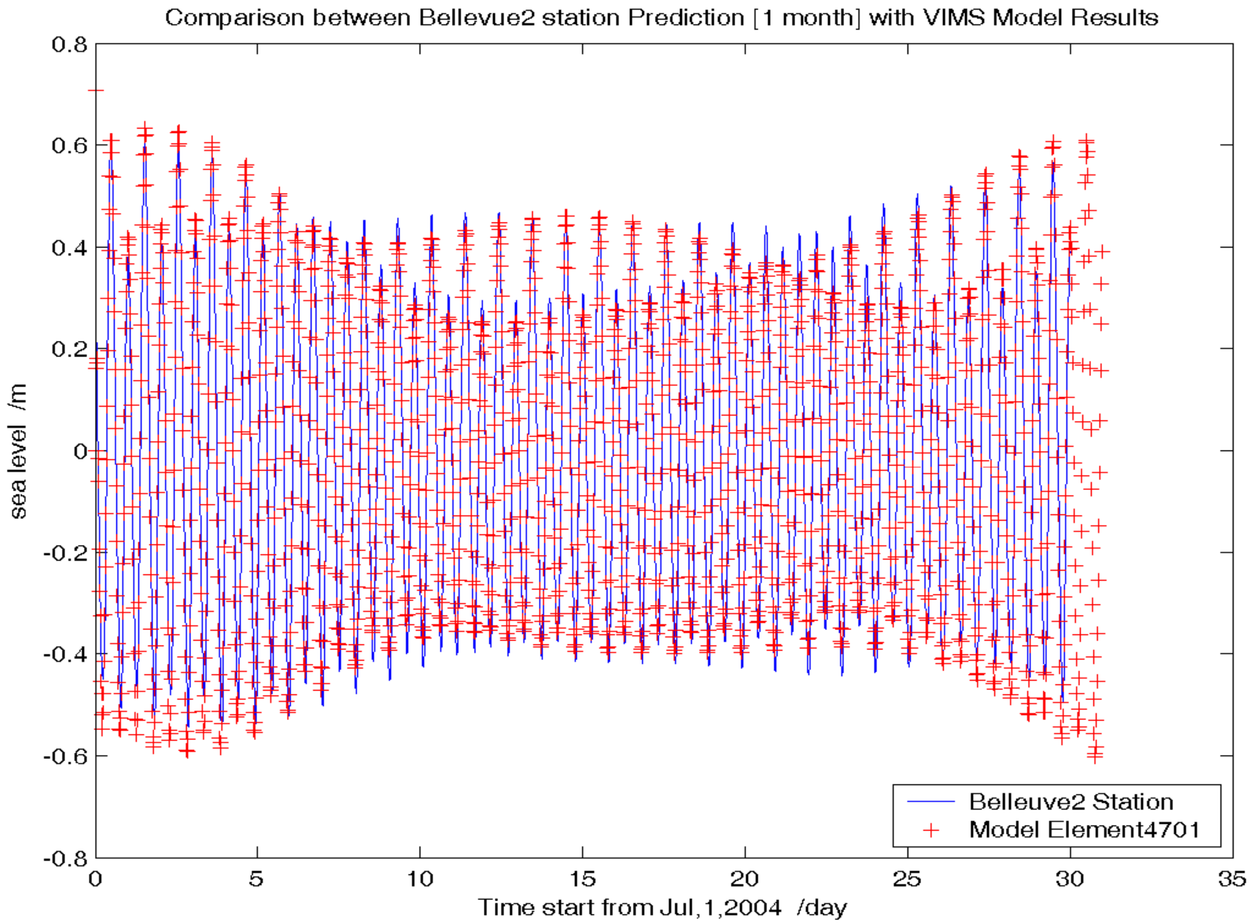


Figure 4 -25: Time series comparison of synthesized astronomical tide and simulated water elevation , July 1- July 31, 2004 (Bellevue2 Station)

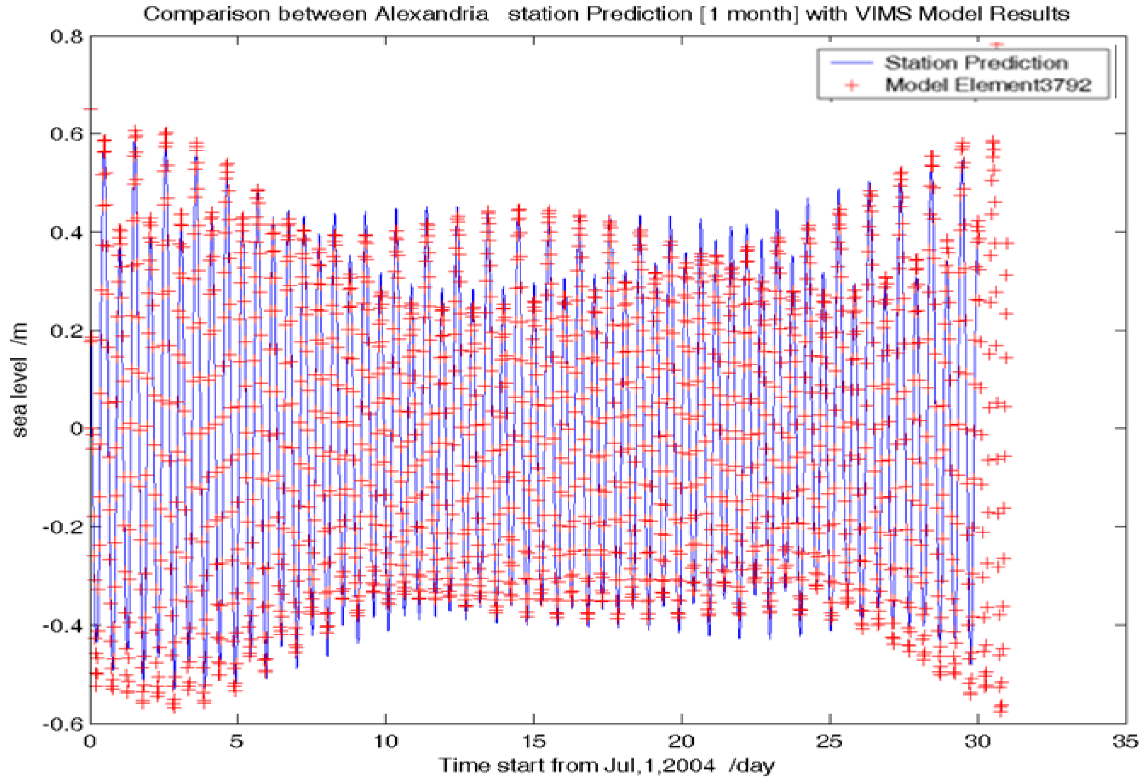


Figure 4 -26: Time series comparison of synthesized astronomical tide and simulated water elevation , July 1- July 31, 2004 (Alexandria Station)

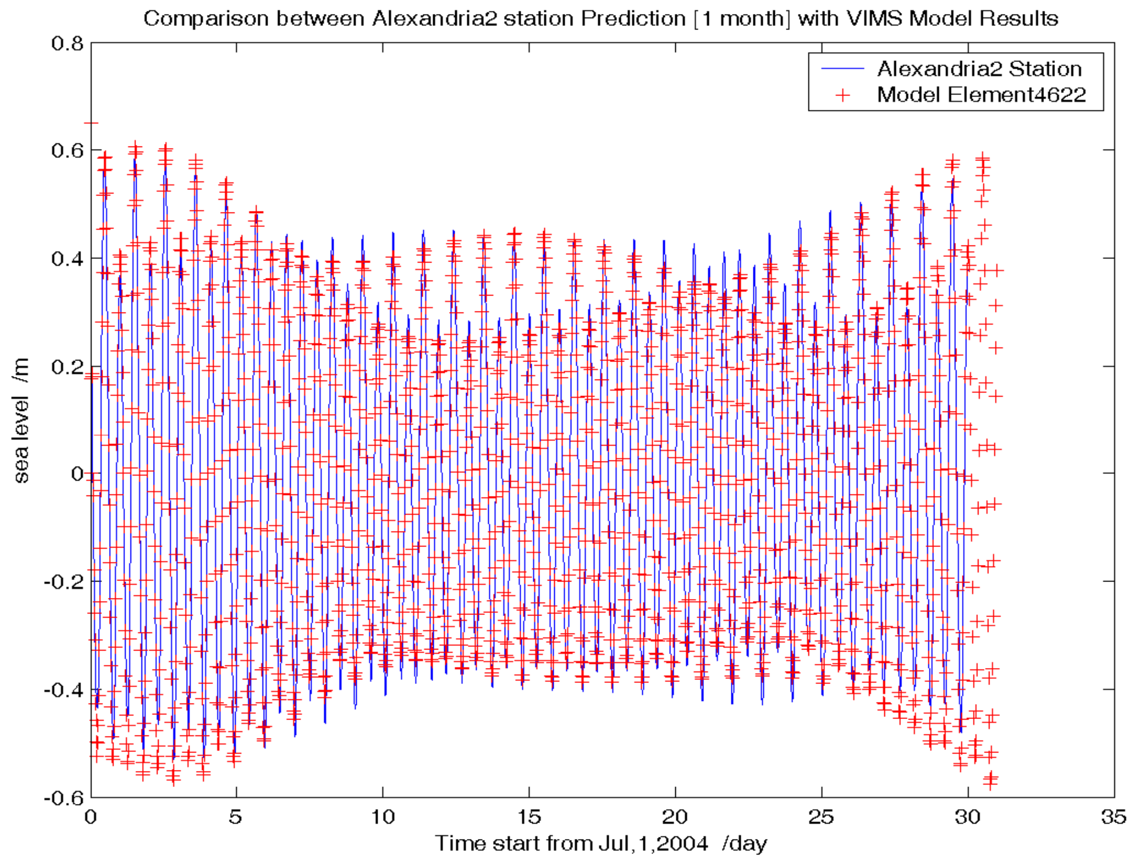


Figure 4 -27: Time series comparison of synthesized astronomical tide and simulated water elevation , July 1- July 31, 2004 (Alexandria2 Station)

It is a well-known fact that when the tide propagates through the narrow inlet, due to the friction and head losses, the tidal amplitude is reduced and the frequency is shifted (Keulegan 1967; US Department of Transportation)**.** The spatial variation of tidal amplitude from outside of Hunting Creek propagating into where Cameron Run meets Hunting Creek was examined. **Figure 4-28** shows the time series of tidal elevation at the City of Alexandria, Potomac River; Richmond Highway bridge crossing, Hunting Creek; and at the Telegraph Road bridge crossing, Cameron Run. It is estimated that the tidal amplitude reduction is about 25 % between the City of Alexandria's site on the Potomac River and the Richmond Highway site on Hunting Creek. The magnitude of the reduction increases to 75% from Richmond Highway, Hunting Creek to Telegraph Road, Cameron Run. This is qualitatively consistent with the tidal records obtained by Cerco and Kuo (1983).

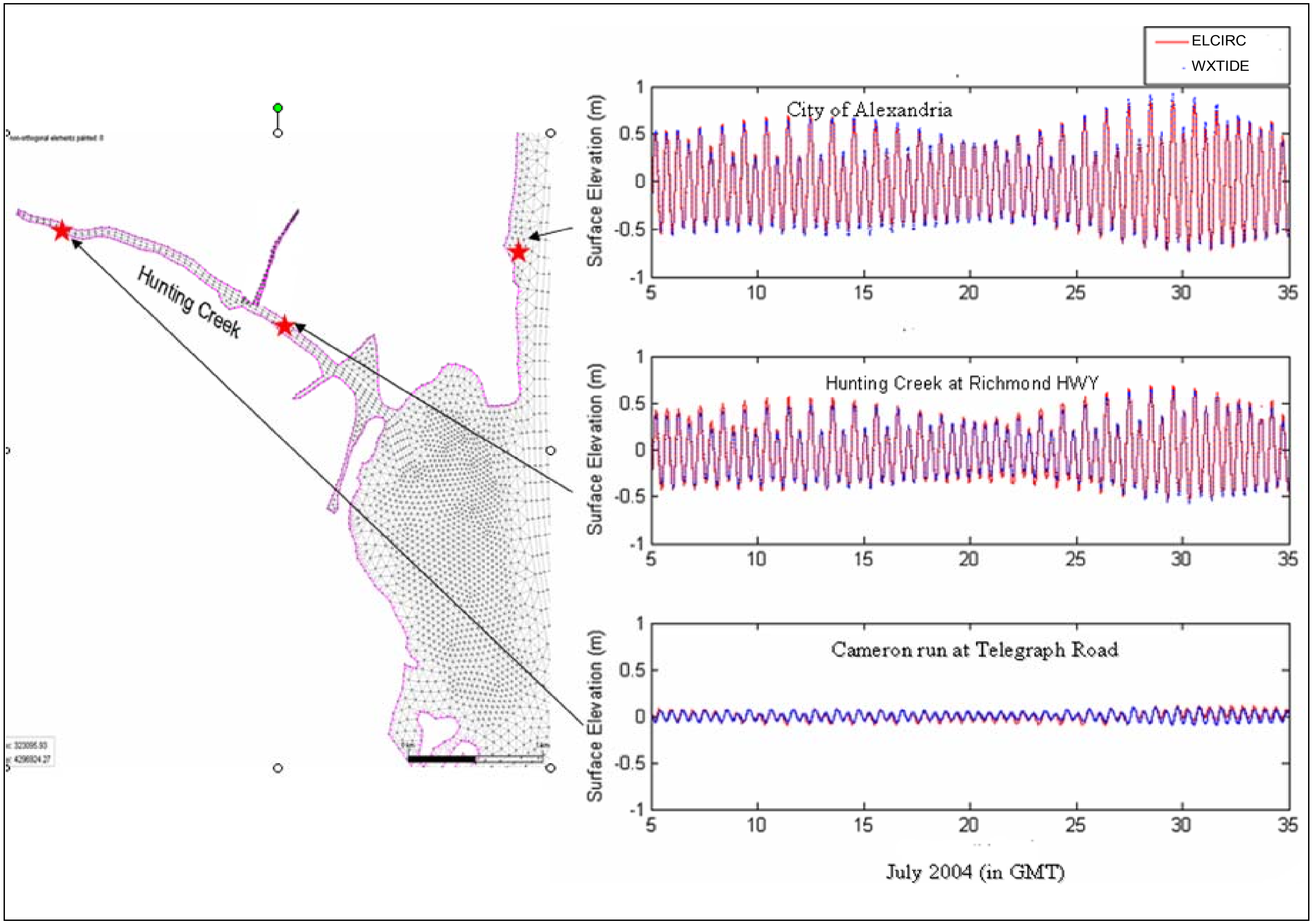


Figure 4-28: Spatial distribution of tidal amplitude from Potomac River, through Hunting Creek into Cameron Run

4.3.6 ELCIRC Fecal Coliform Bacteria Calibration

Observed bacteria concentrations were available during the 2001-2003 calibration period and the 2004 -2005 verification period at five locations: BSL-1, BSL-2, BS-3, 1AHUT000.01, and PMS44. 1AHUT000.01, at the G. W. Parkway is the primary VADEQ monitoring station in Hunting Creek. BSL-1, BSL-2, and BSL-3 are COA stations where monitoring data is collected as part of the CSS permit. PMS44 is a DCDOE ambient monitoring station. The bacteria monitoring data from these stations is discussed in more detail in Section 3.3. The monitoring stations are shown in Figure 4-29 in relation to the major sources of bacteria into Hunting Creek and the Potomac River. These major sources include, as the COA CSO outfalls, WWTPs, and the confluence of Hunting Creek with non-tidal Cameron Run and other tributaries to the embayment. The goal of the fecal coliform bacteria concentration calibration is to simulate the observed distribution of bacteria concentrations at each of these locations.

Bacteria concentrations are a function of three factors: (1) bacteria loading rates; (2) advection and dispersion of bacteria during hydrodynamic transport; and (3) the die-off or decay of bacteria during the transport process. Section 4.2 discusses the bacteria loading rates used in the ELCIRC model. Advection and dispersion are functions of the hydrodynamic simulation discussed in Section 4.3.5. The animation of computer model simulation results shows that high concentrations of bacteria discharged into Hunting Creek act like a tidal plume throughout the embayment before they are mixed into the Potomac River (VADEQ, Hunting Creek TAC Meeting#3 Presentation). The primary focus of the calibration of the bacteria simulation is the specification of the bacteria decay rate. Preliminary calibration simulations indicated that adding a temperature correction to the decay rate would not improve model performance, so no temperature correction was applied to the simulated decay rate.

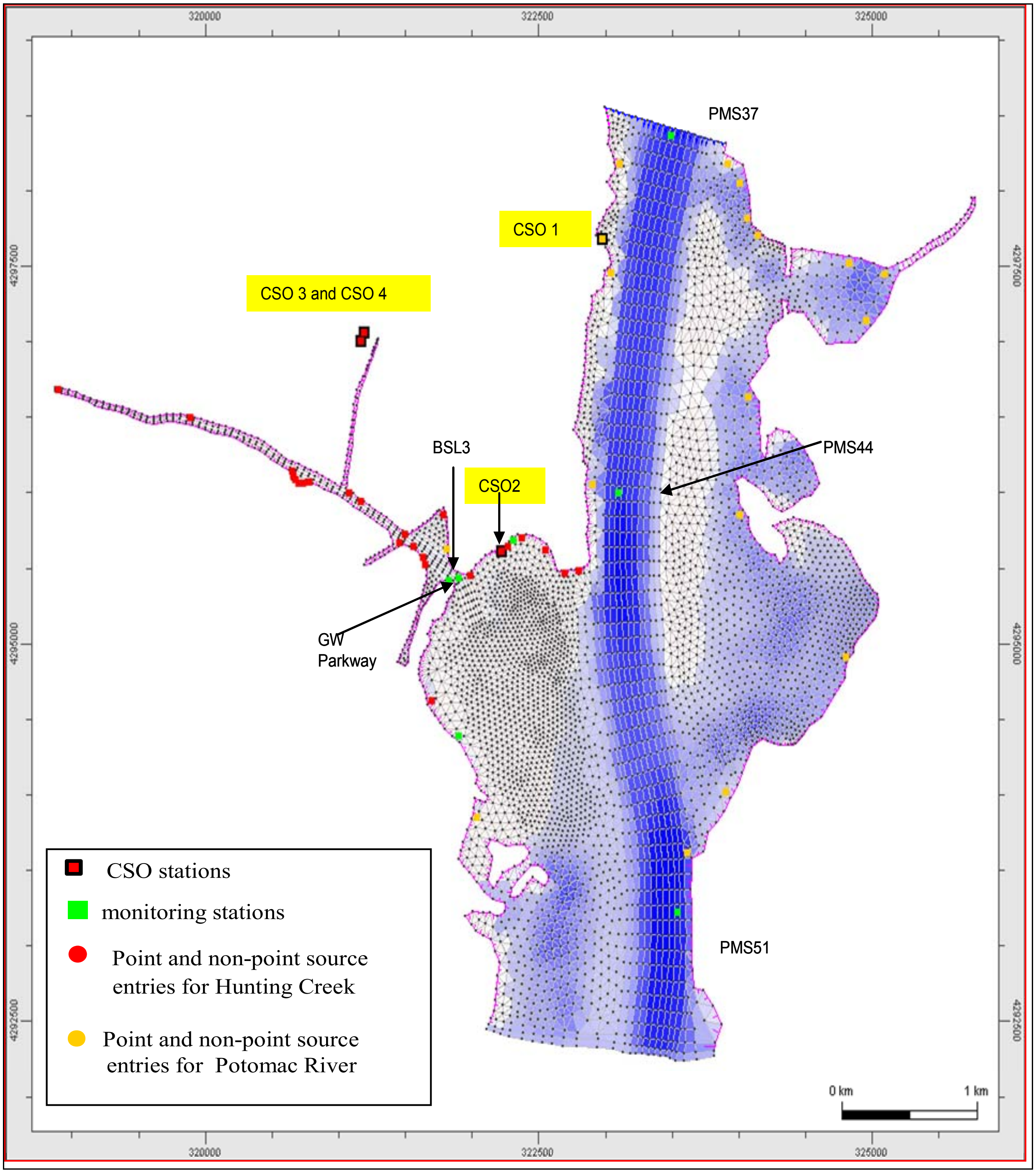


Figure 4-29: Non-point source discharge locations, CSOs, and monitoring station locations

Since fecal coliform data are highly variable both temporally and spatially, a one-to-one comparison of observed and simulated concentrations is rarely meaningful. The goal of the calibration is to determine the value of the decay rate for which the distribution of simulated concentrations matches the distribution of bacteria concentrations observed at each monitoring station. The visual statistical tools such as box-and-whisker plots were used to compare observed and simulated distributions. During the calibration, five different decay rates (0.1, 0.2, 0.3, 0.6 and 0.9 d^{-1}) were simulated and compared to observed monitoring data. **Figures 4-30, 4-31, 4-32, 4-33,** and **4-34** show box-and-whisker plots for simulated and observed data at each primary monitoring station for 2003, the calibration year with the richest data set, using the five different decay rates. On the box-and-whisker plots, the red line represents the median value, and the upper and lower bar represent the 75 percentile and 25 percentile of the data distribution, respectively. As can been seen from the following figures, the simulation which uses a decay rate of 0.1 /day best matches the distribution of the observed data at each monitoring station.

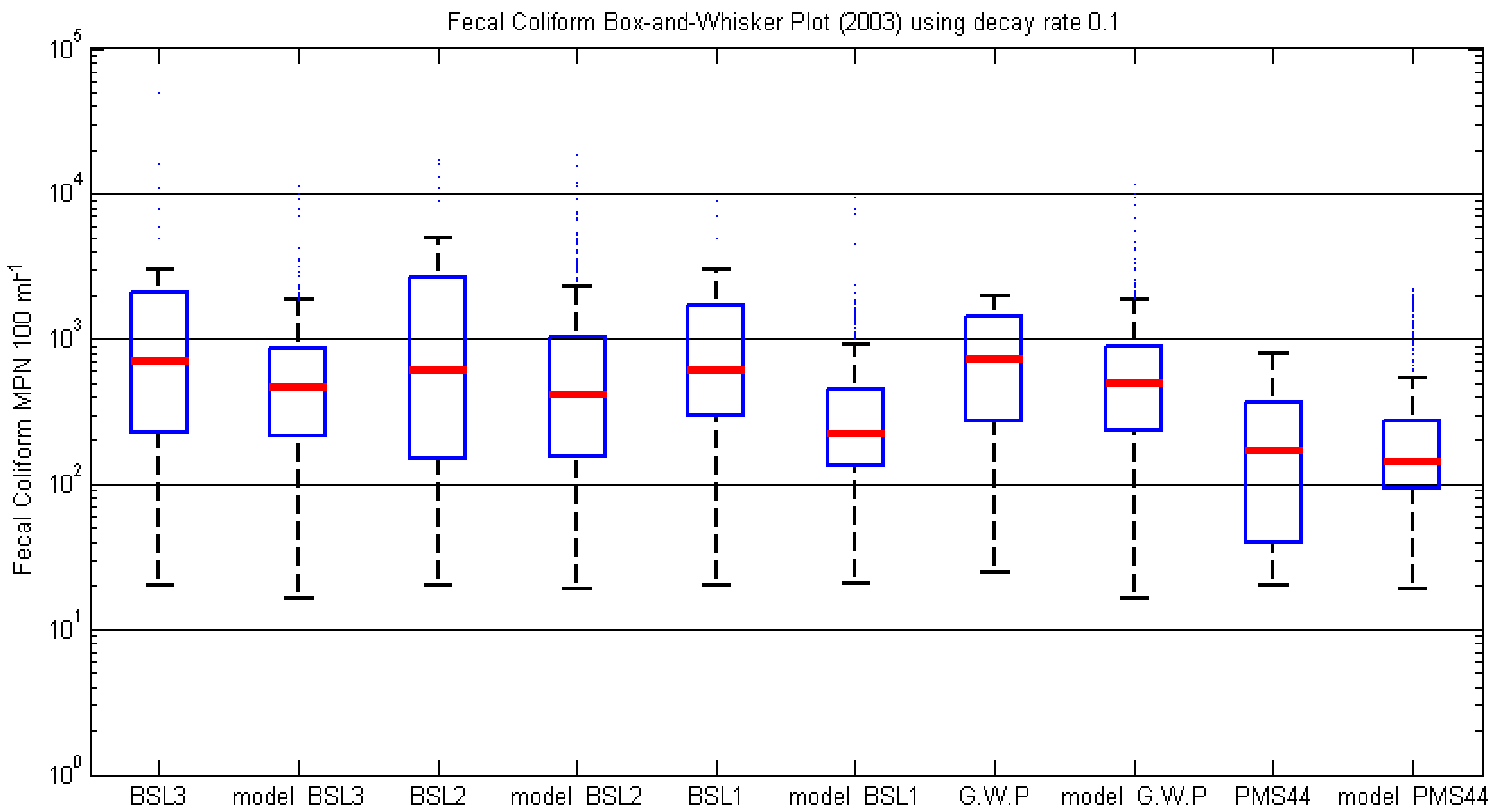


Figure 4-30: Box-and-Whisker plot for sensitivity test of decay rate of 0.1(/day) in 2003

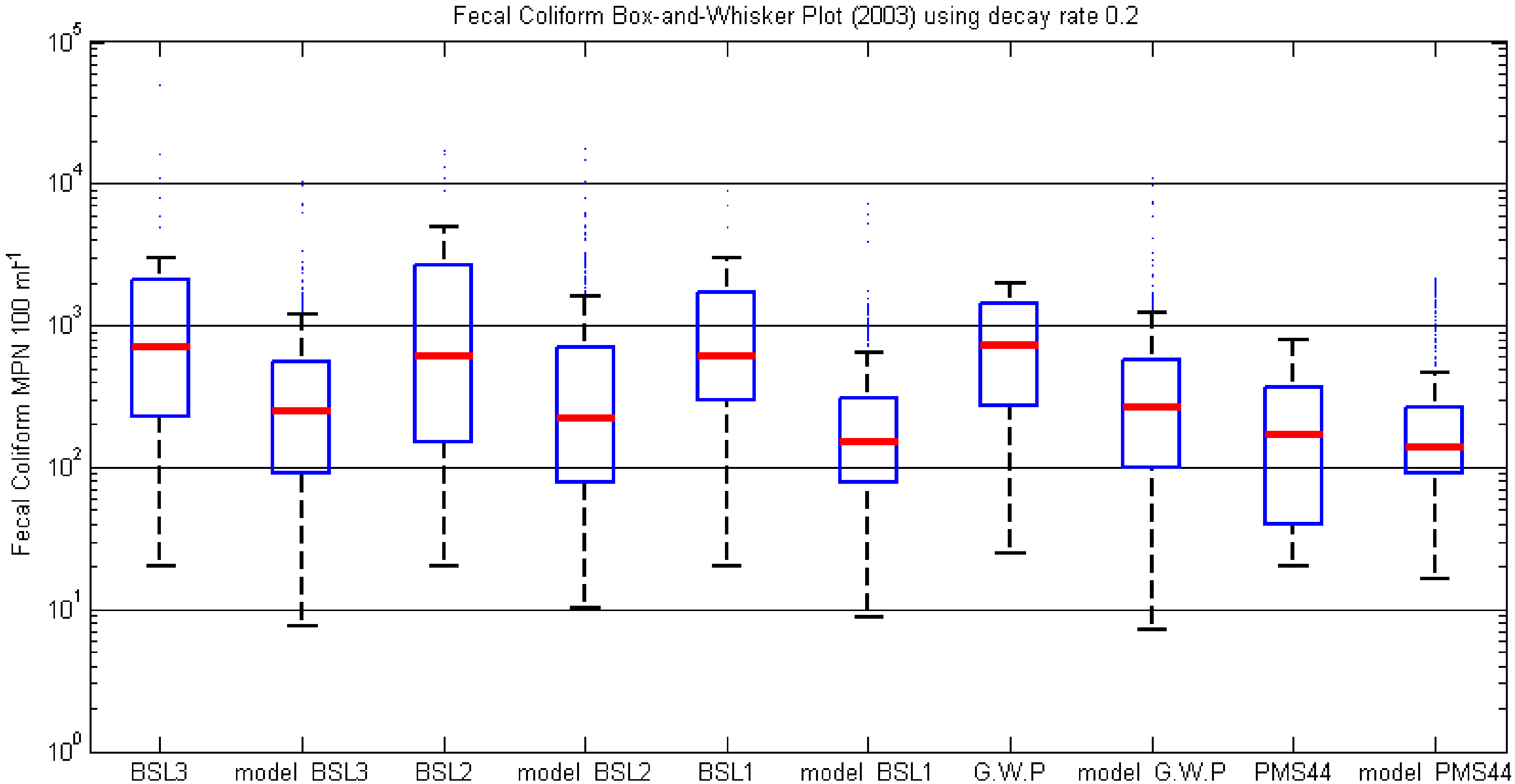


Figure 4-31: Box-and-Whisker plot for sensitivity test of decay rate of 0.2(/day) in 2003

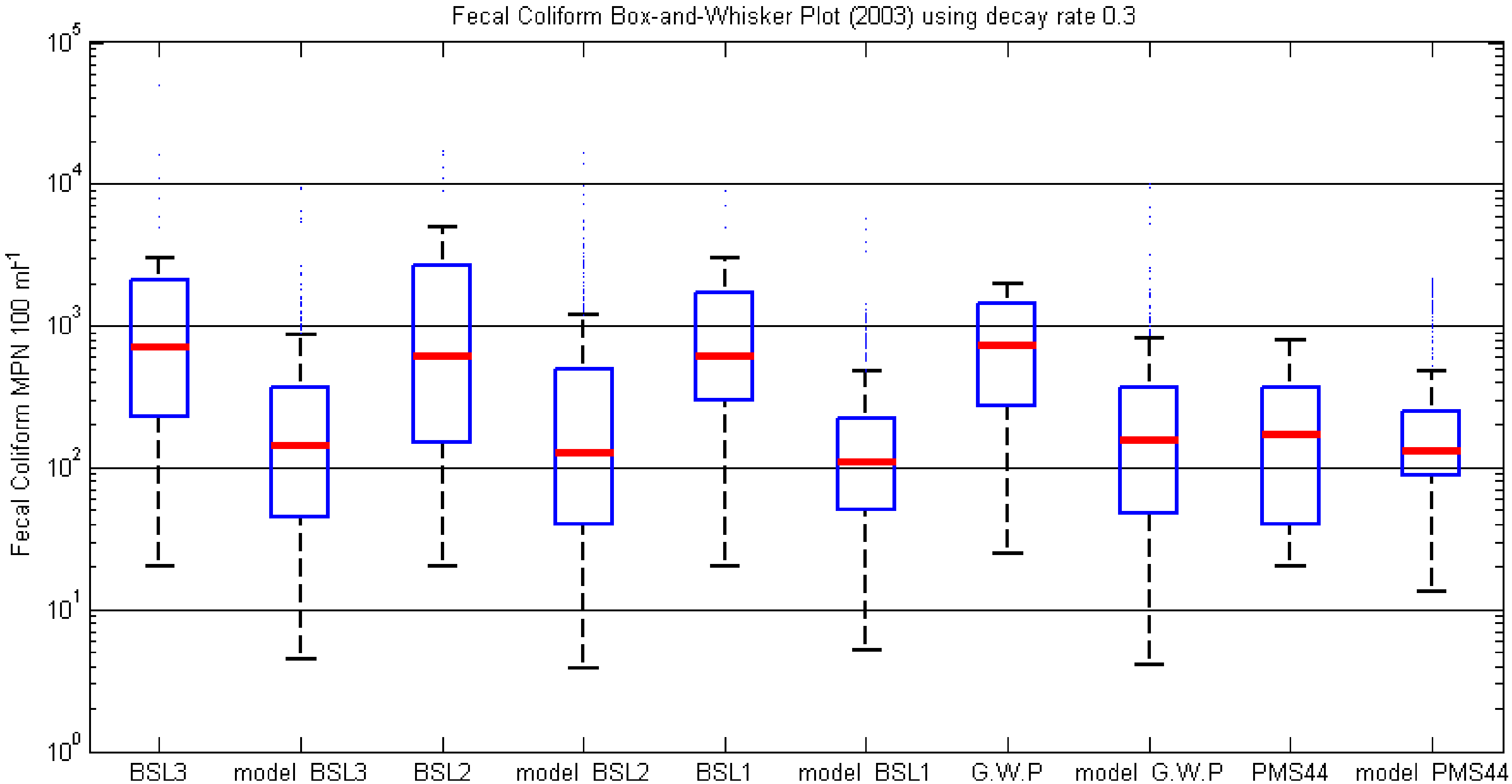


Figure 4-32: Box-and-Whisker plot for sensitivity test of decay rate of 0.3(/day) in 2003

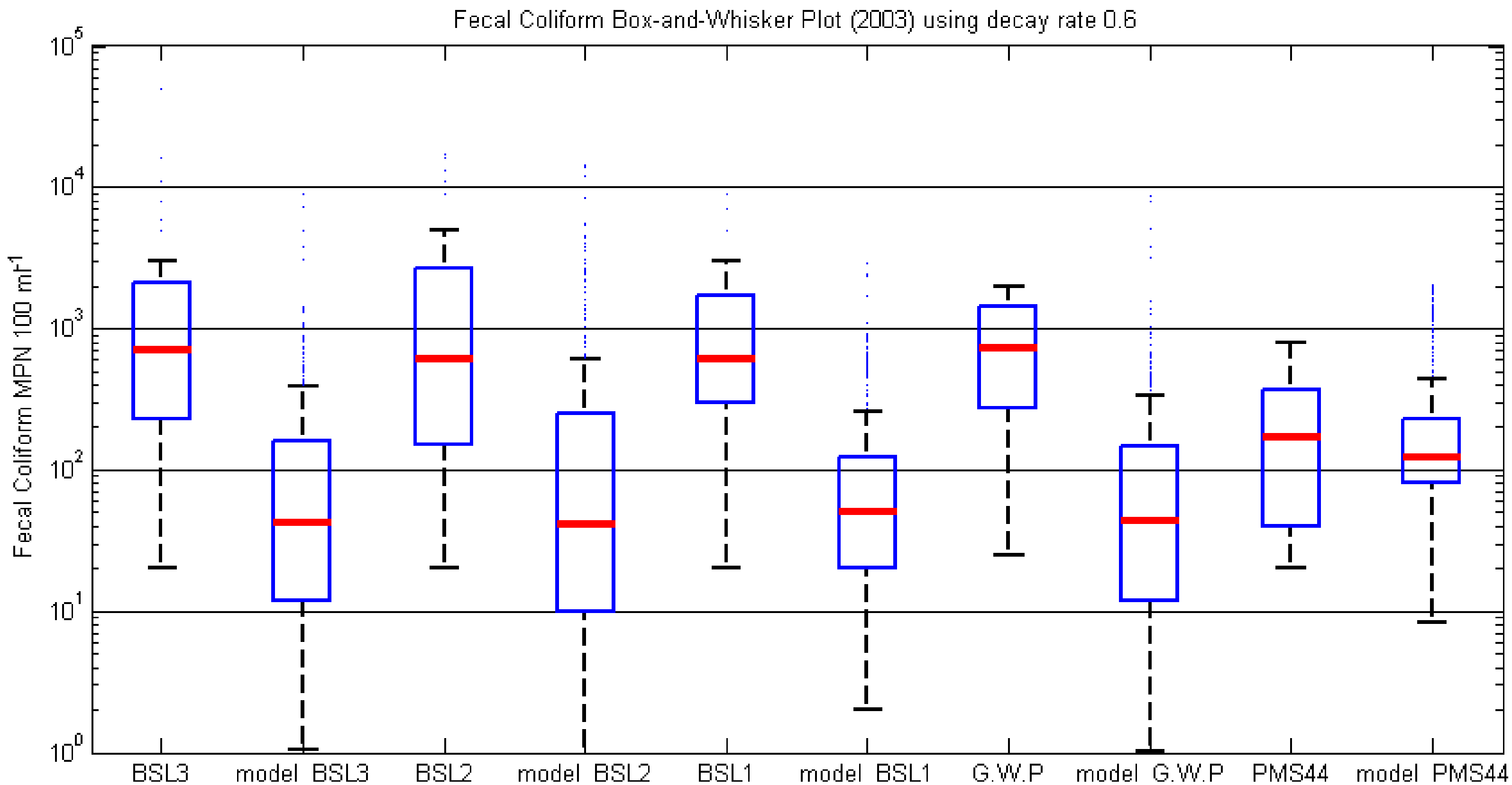


Figure 4-33: Box-and-Whisker plot for sensitivity test of decay rate of 0.6(/day) in 2003

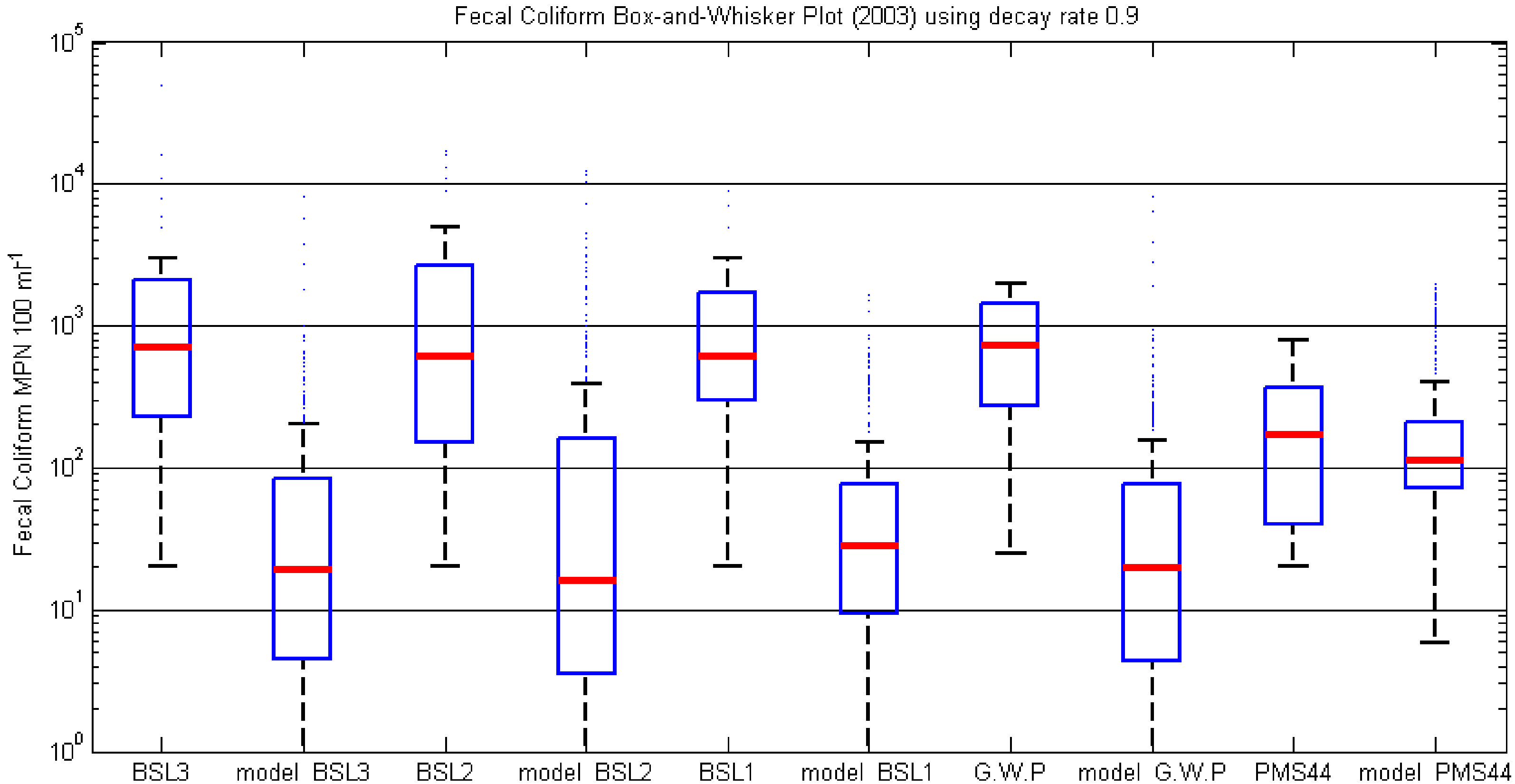


Figure 4-34: Box-and-Whisker plot for sensitivity test of decay rate of 0.9(/day) in 2003

Observed bacteria concentrations were compared to the daily average bacteria concentration simulated at the cell in which the monitoring station is located. The simulated daily average concentration was computed as the arithmetical average of hourly concentrations, as recommended by VADEQ guidance (VADEQ, 2003). Time series comparing the simulated daily average concentration and the observed concentrations were also generated. **Figures 4-35, 4-36, 4-37, 4-38**, and **4-39** compare the time series observed and simulated bacteria concentrations at stations BSL1, BSL2, BSL3, GW Parkway and PMS44 for 2003, using a decay rate of 0.1 /day. Figure 4-40 shows a box-and-whisker plot for the calibration year 2003. The red dots on the following five figures represent actual, observed data. The pink dots represent modeled, monthly, geometric means.

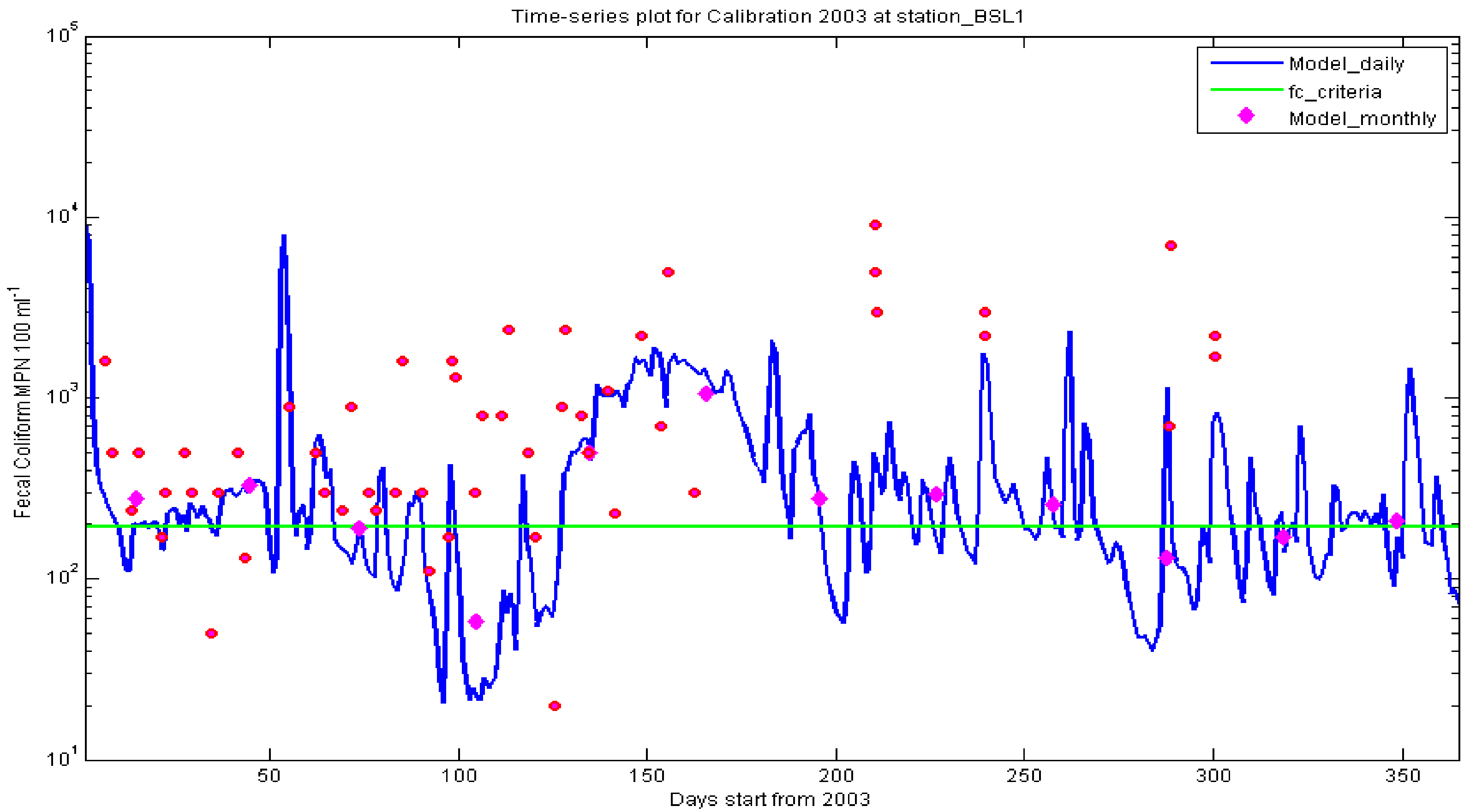


Figure 4-35: Time Series Comparison between Observed and Modeled Data at Station BSL1 (2003, decay rate of 0.1/day)

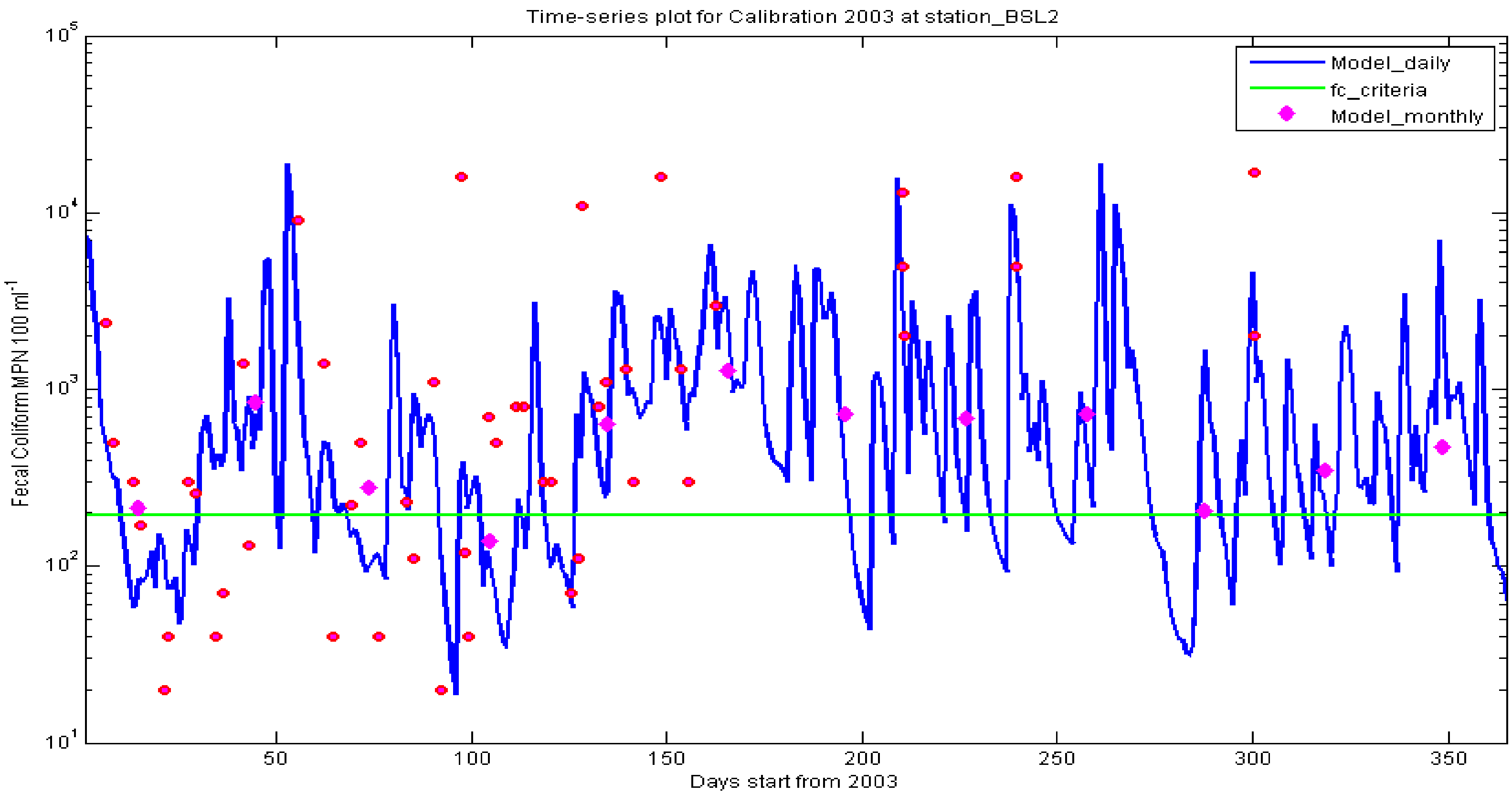
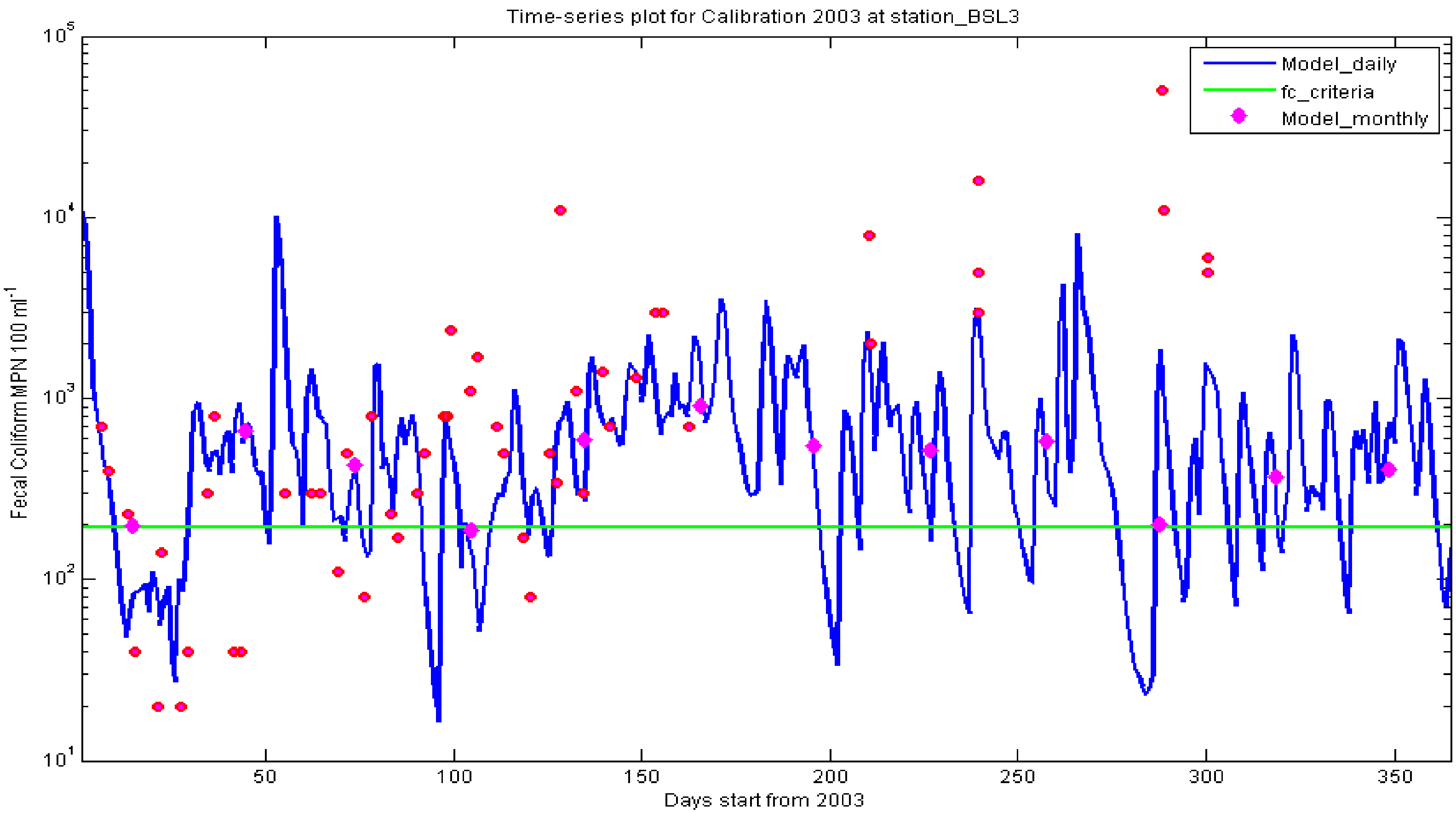
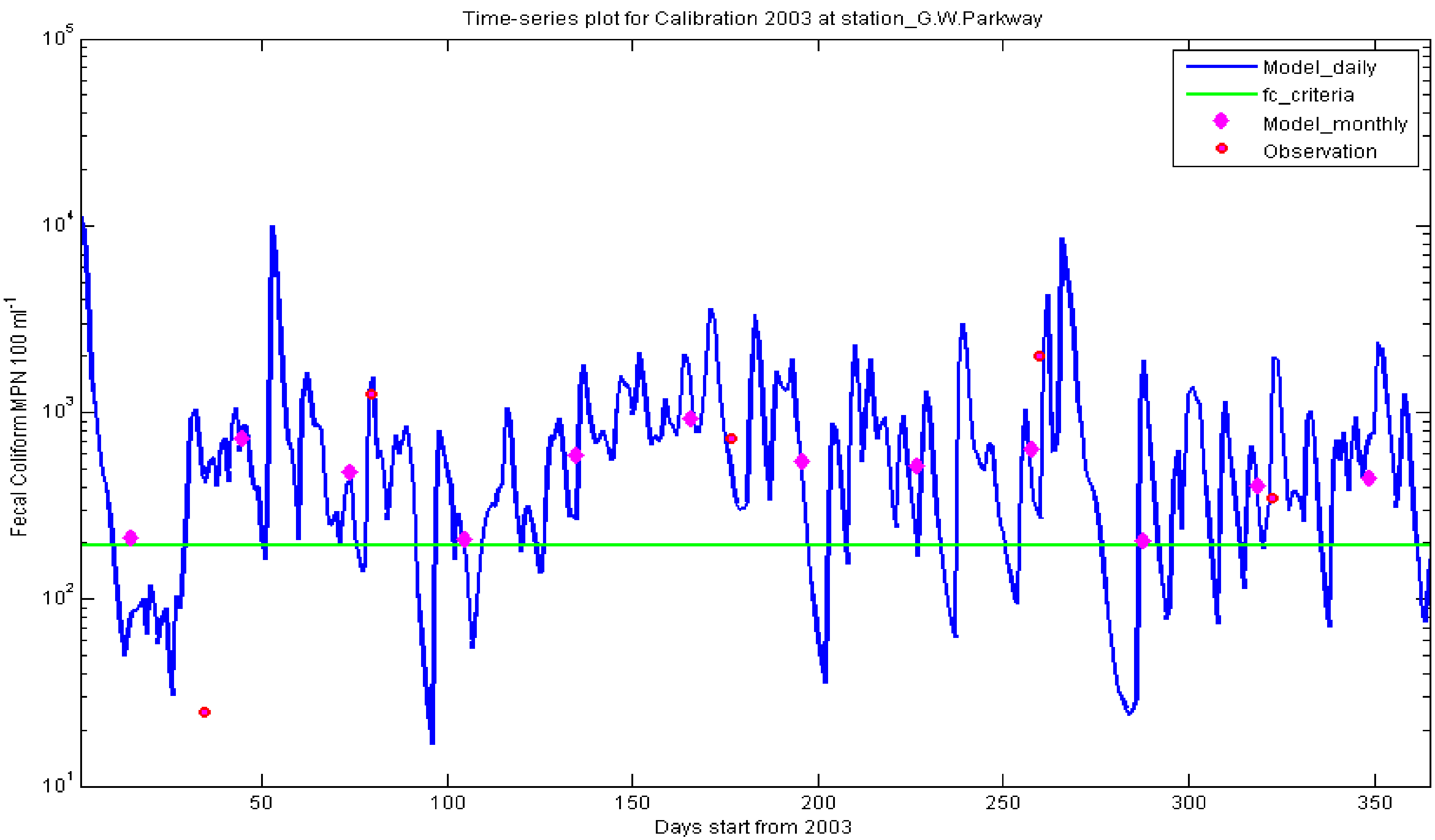


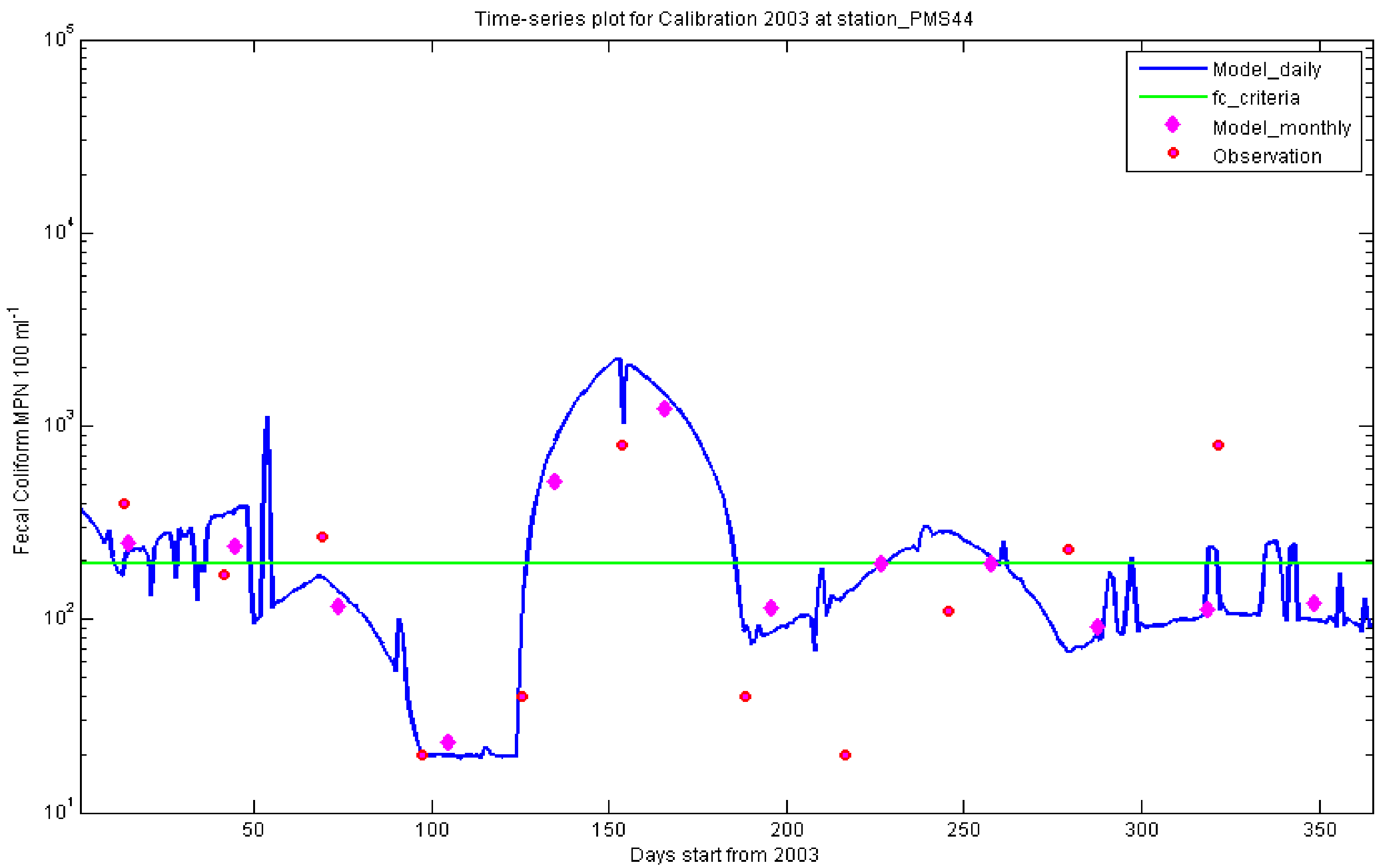
Figure 4-36: Time Series Comparison between Observed and Modeled Data at Station BSL2 (2003, decay rate of 0.1/day)



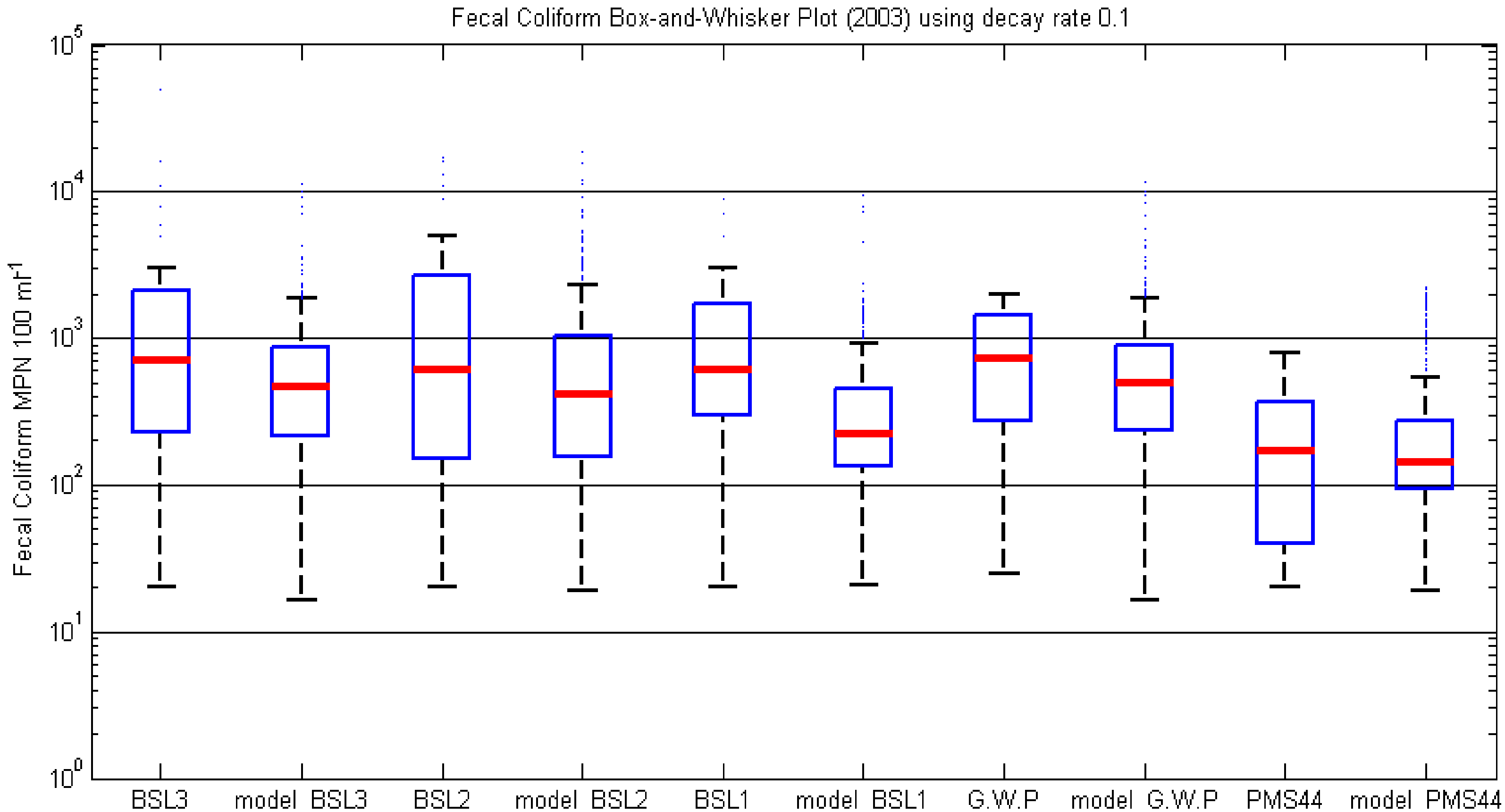
4-37: Time Series Comparison between Observed and Modeled Data at Station BSL3 (2003, decay rate of 0.1/day)



4-38: Time Series Comparison between Observed and Modeled Data at the DEQ GW Parkway Station (2003, decay rate of 0.1/day)



4-39: Time Series Comparison between Observed and Modeled Data at the PMS44 (2003, decay rate of 0.1/day)



4-40: Box-and-Whisker Plot for the Calibration Year 2003

Figures 4-41 and **4-42** show box-and-whisker plots for the validation years 2004 and 2005, respectively. **Figures 4-43, 4-44, 4-45, 4-45**, and **4-46** show time series plots for the validation year 2004. **Figures 4-47, 4-48, 4-49, 4-50**, and **4-51** show time series plots for the validation year 2005. The red dots on the time series figures represent actual, observed data. The pink dots represent modeled, monthly, geometric means. Both series of plots show that the bacteria simulation using a decay rate 0.1 /day continues to maintain a good fit with the distribution of the observed data during the verification period.

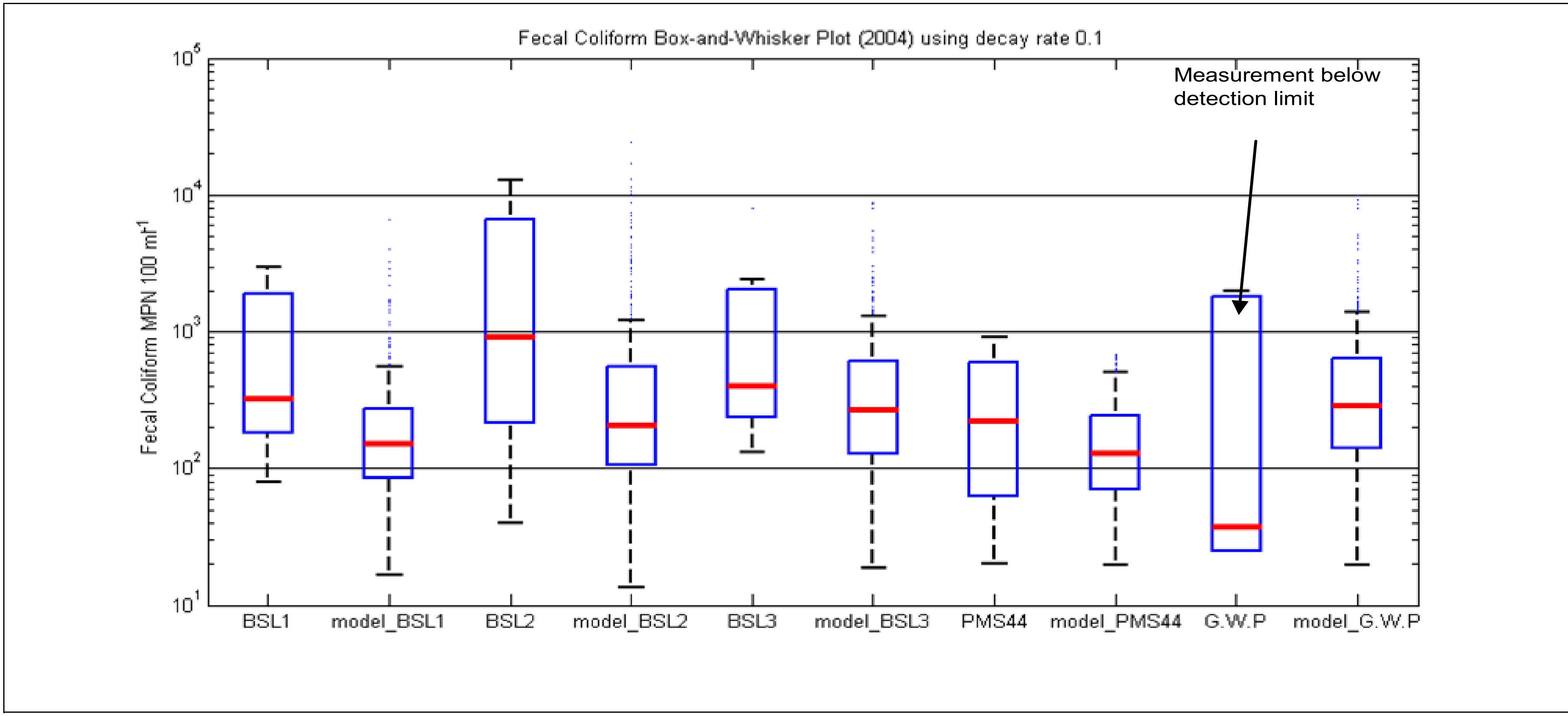


Figure 4-41: Box-and-Whisker plot of observed and modeled fecal coliform for 2004

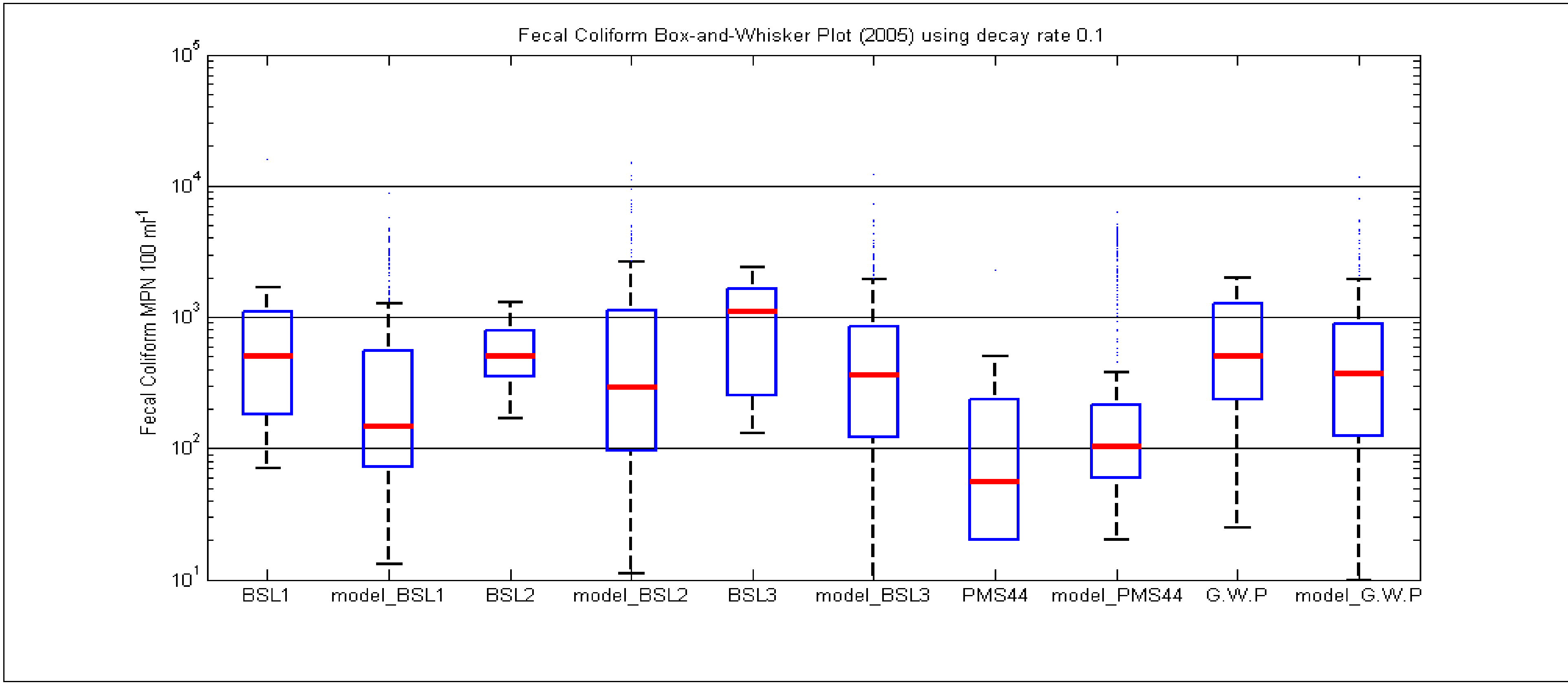


Figure 4-42: Box-and-Whisker plot of observed and modeled fecal coliform for 2005

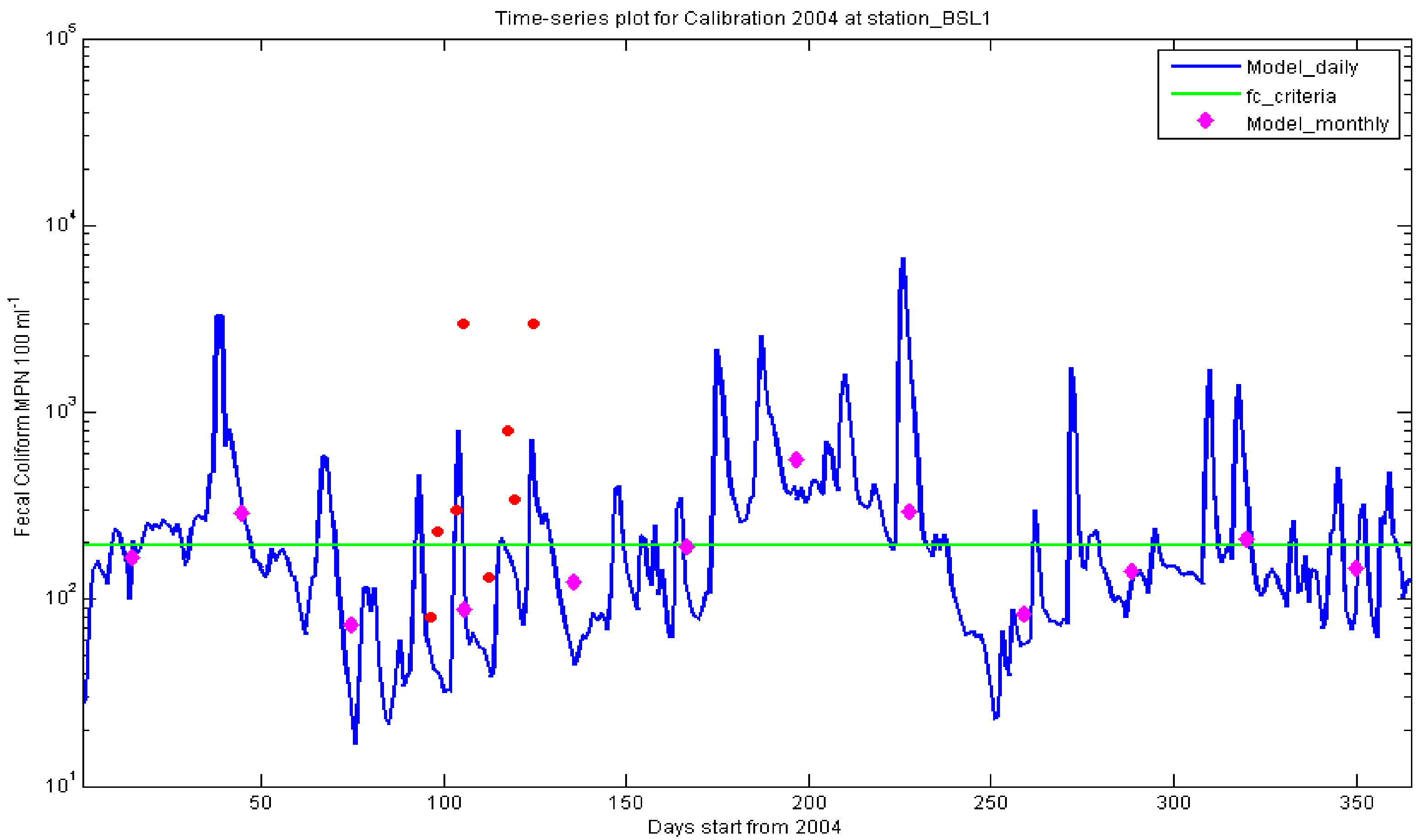


Figure 4-43: Time series of observed and modeled fecal coliform for 2004 at Station BSL1

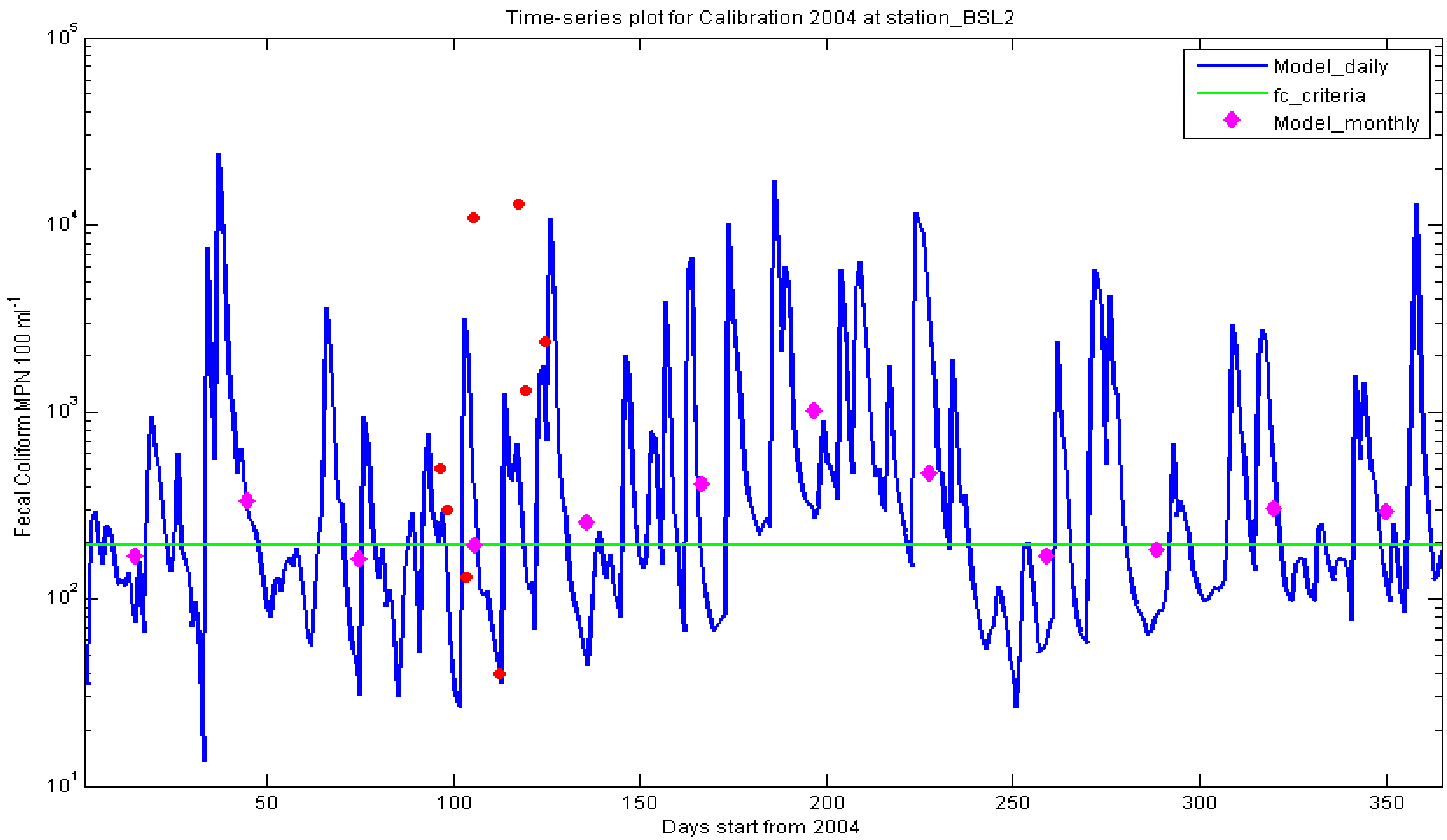


Figure 4-44: Time series of observed and modeled fecal coliform for 2004 at Station BSL2

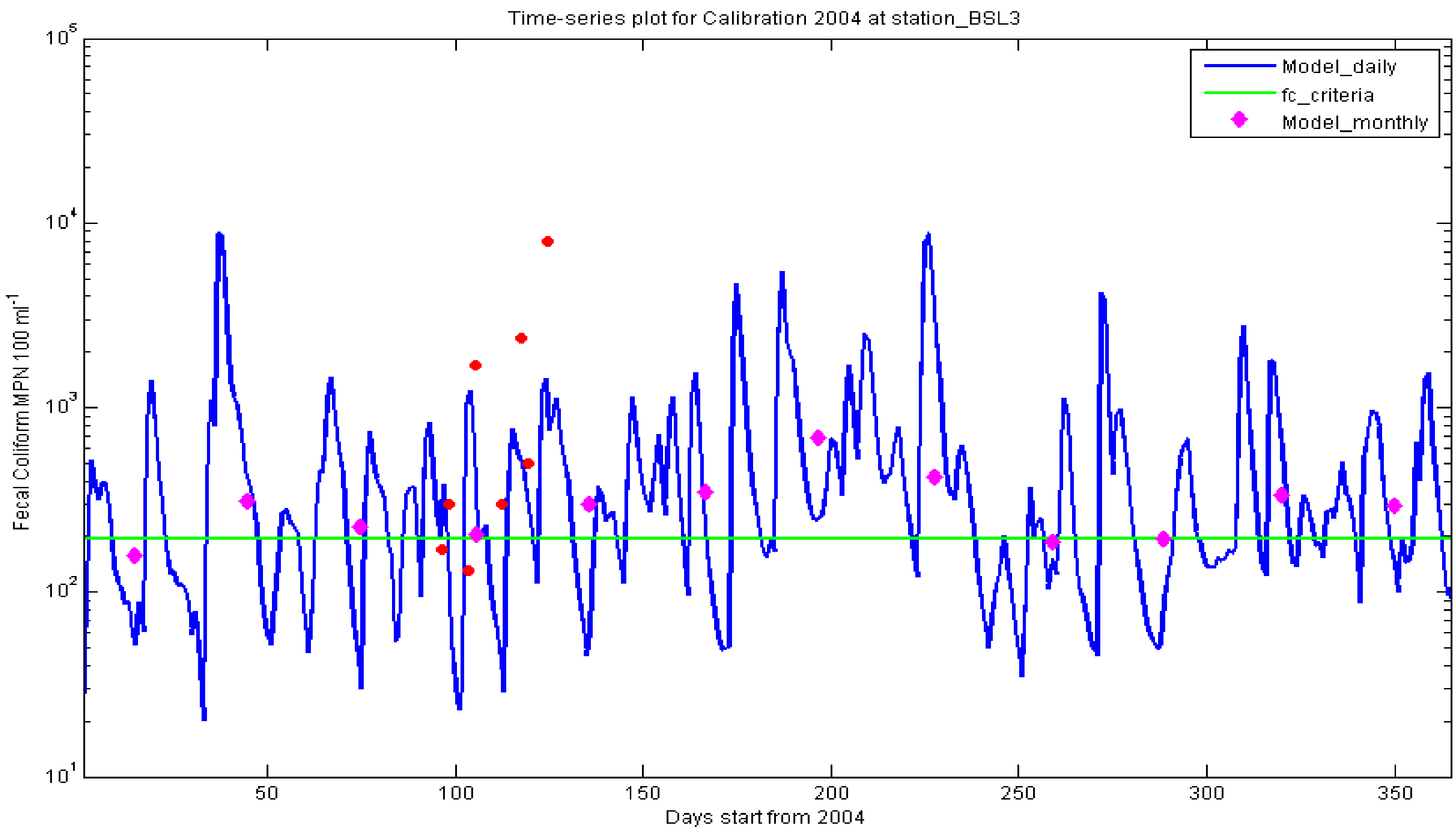


Figure 4-45: Time series of observed and modeled fecal coliform for 2004 at Station BSL3

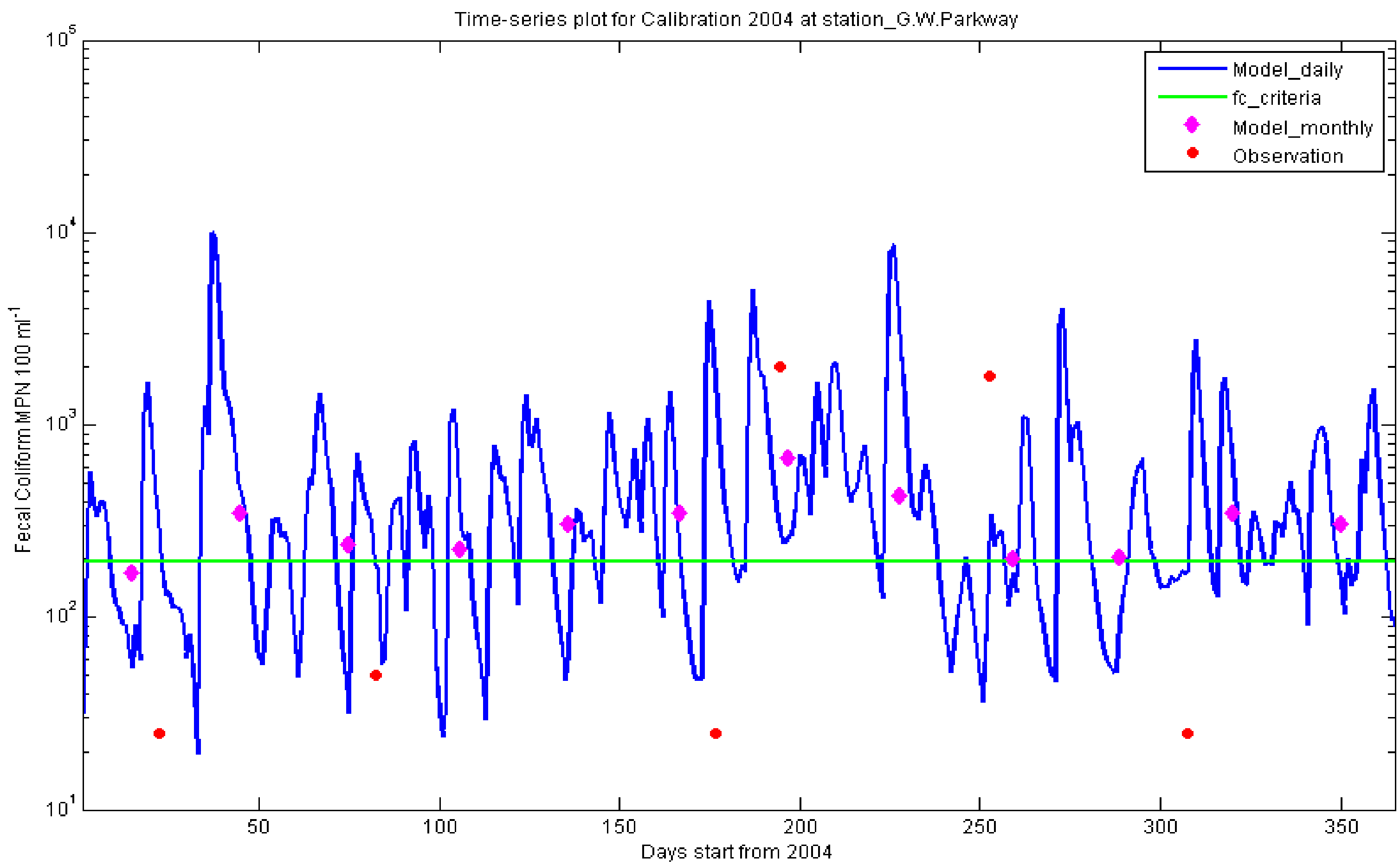


Figure 4-46: Time series of observed and modeled fecal coliform for 2004 at the DEQ GW Parkway Station

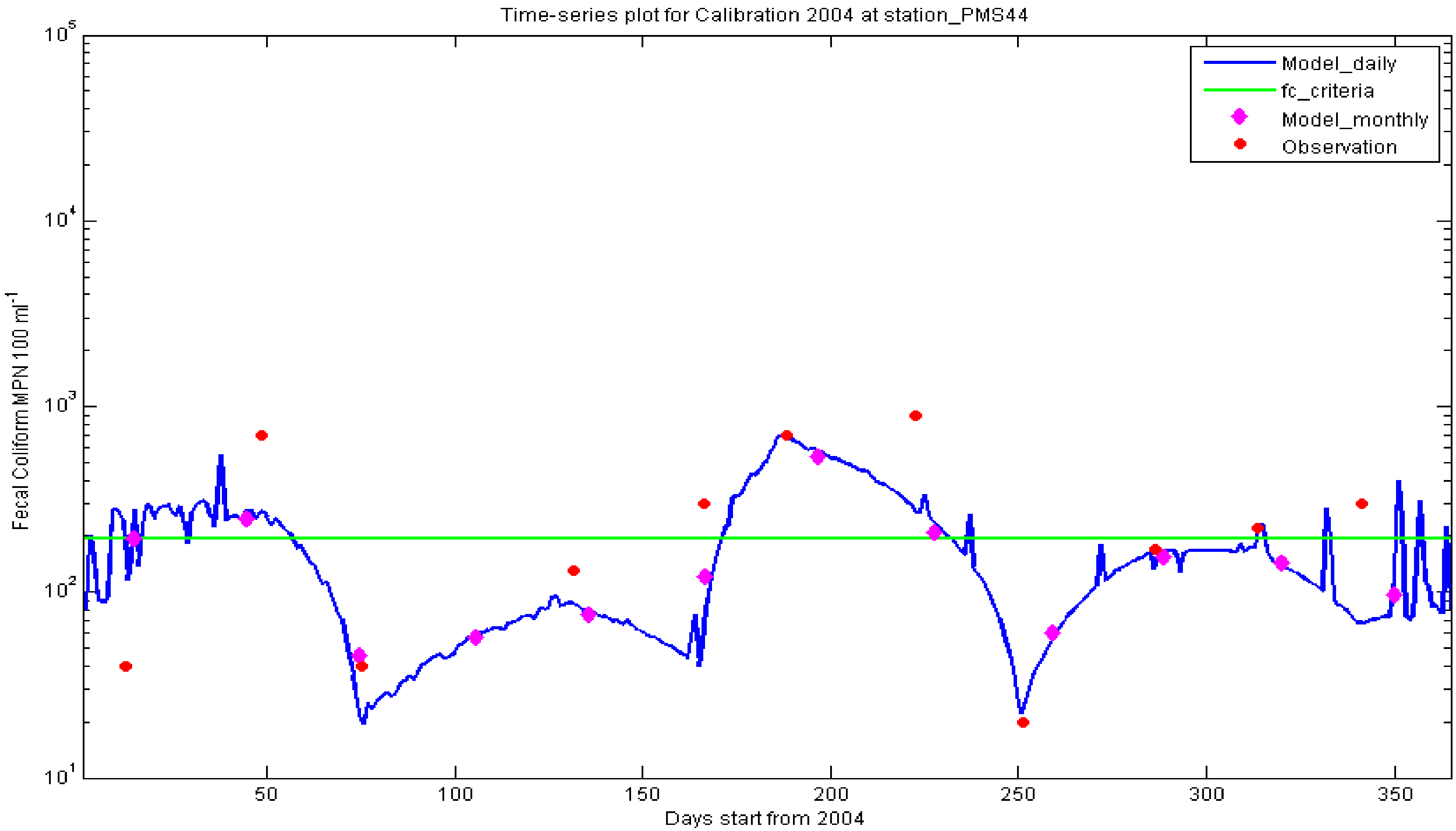


Figure 4-47: Time series of observed and modeled fecal coliform for 2004 at PMS44

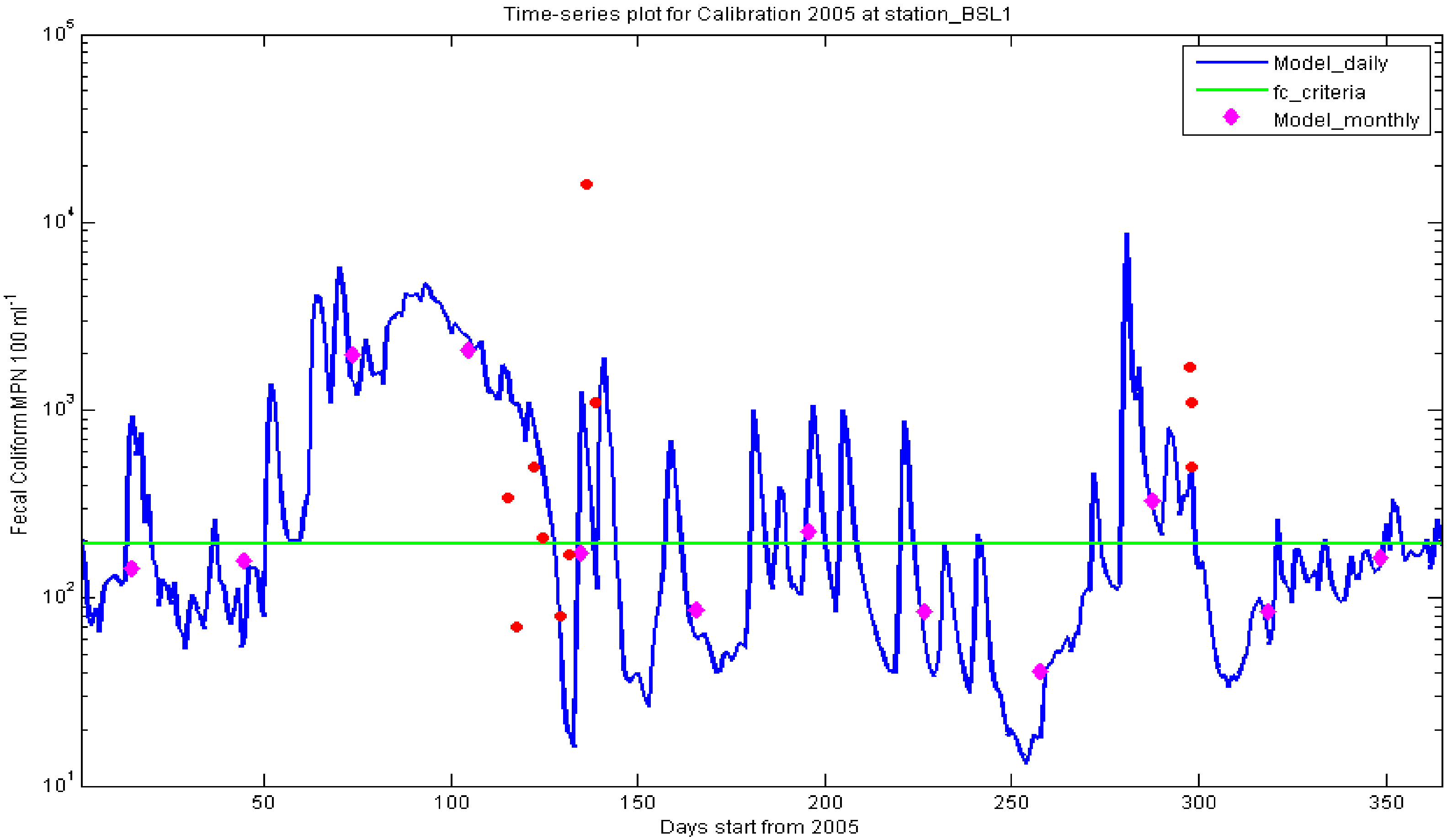


Figure 4-48: Time series of observed and modeled fecal coliform for 2005 at BSL1

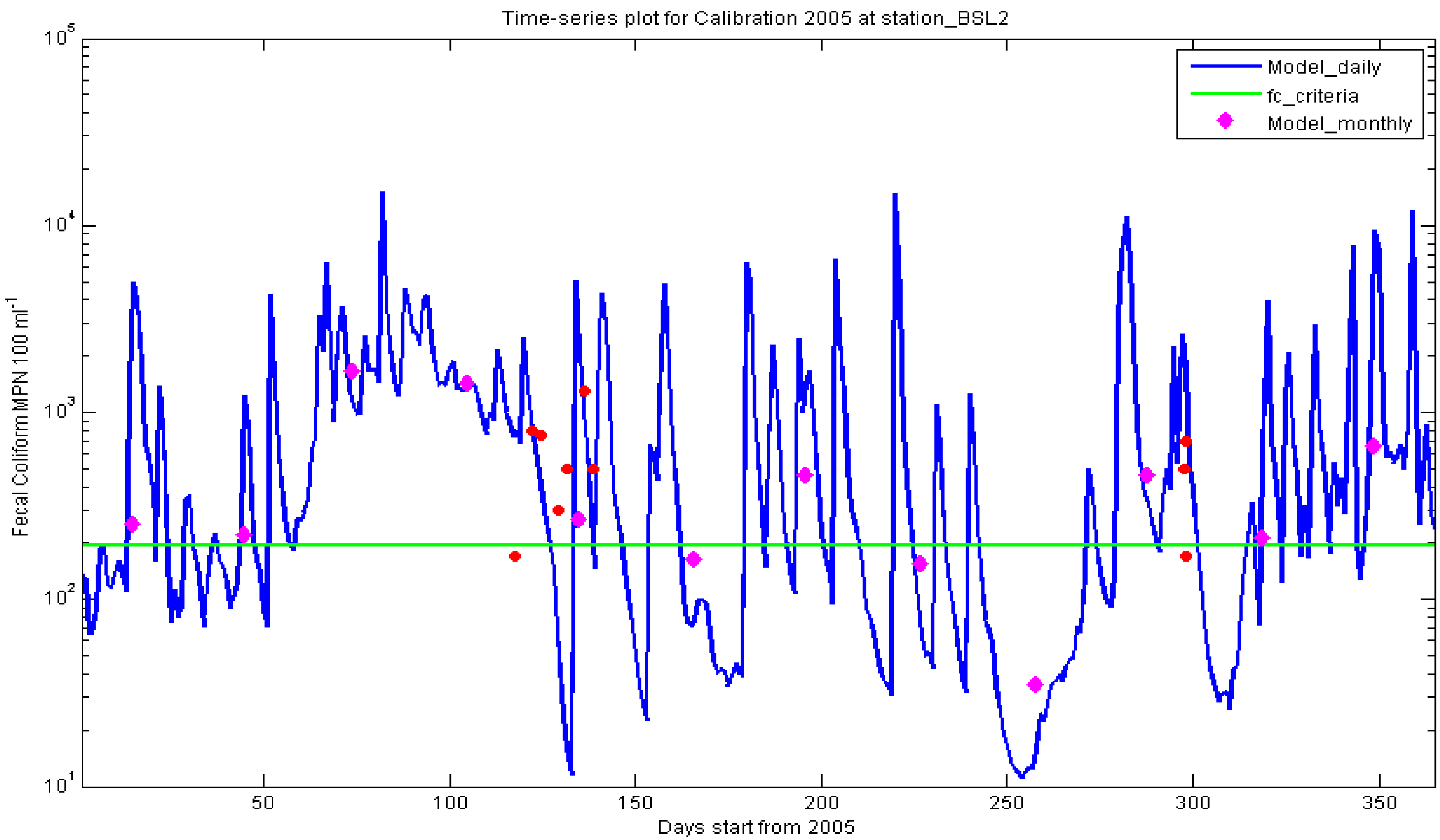


Figure 4-49: Time series of observed and modeled fecal coliform for 2005 at BSL2

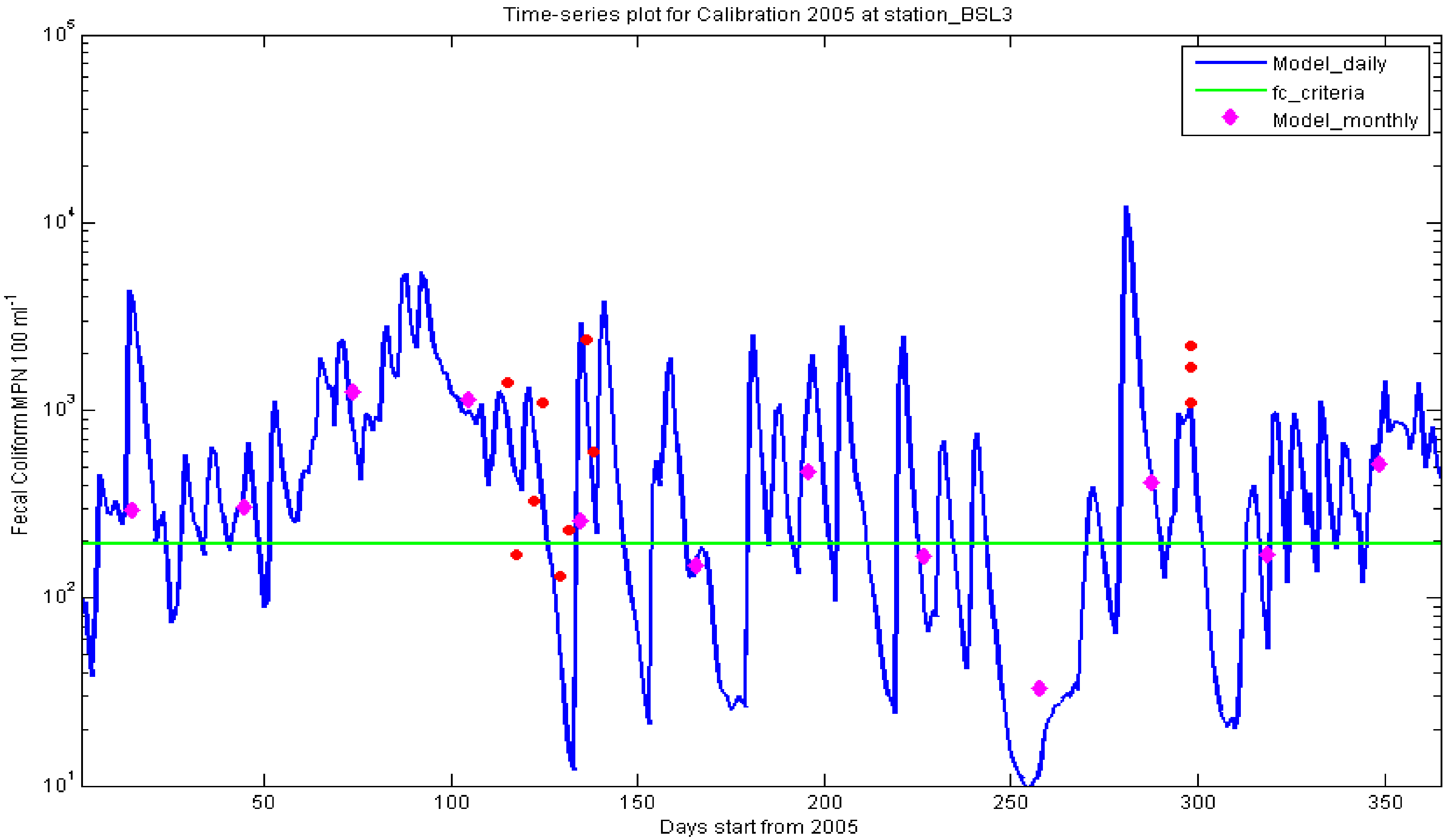


Figure 4-50: Time series of observed and modeled fecal coliform for 2005 at BSL3

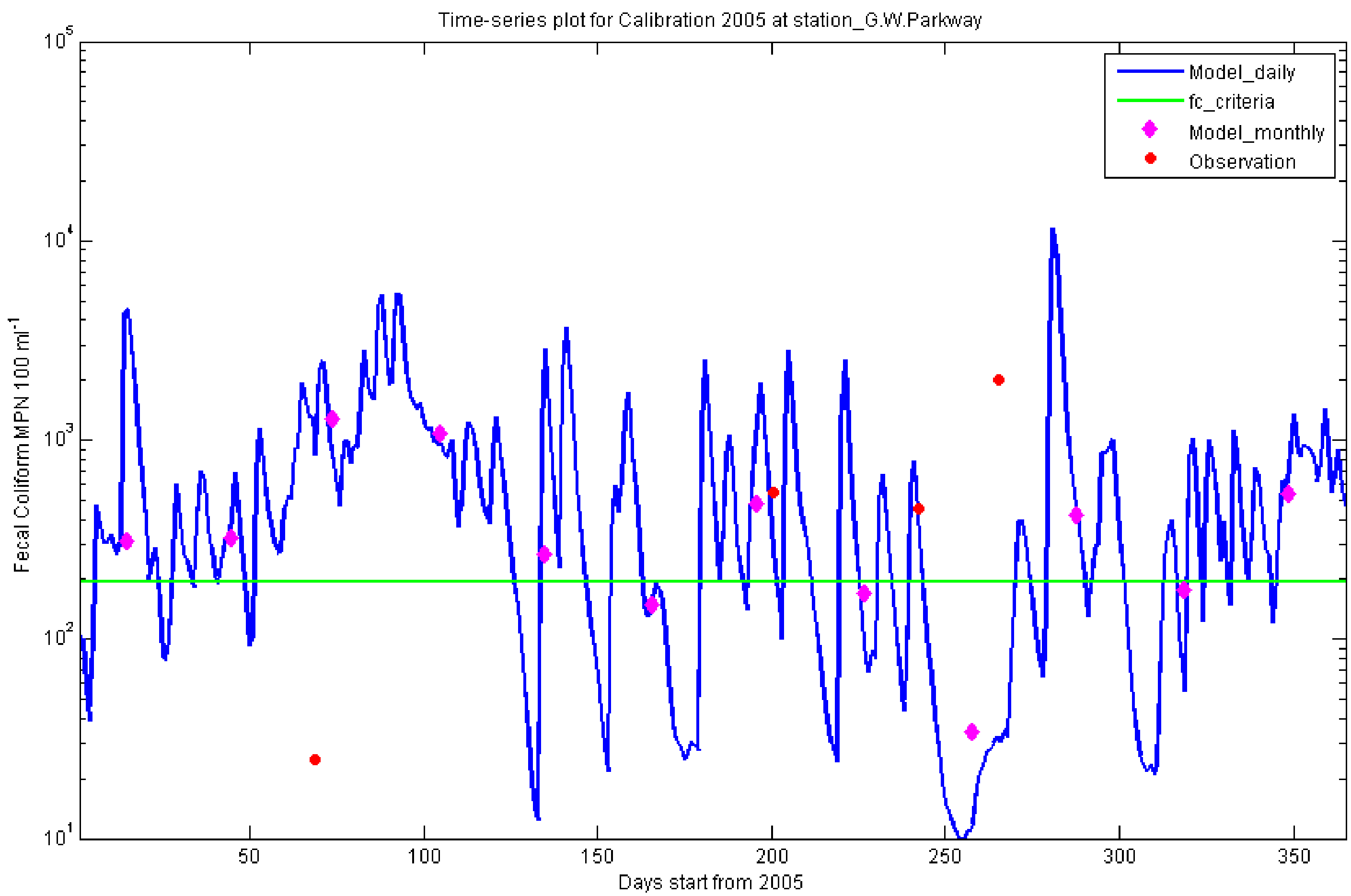


Figure 4-51: Time series of observed and modeled fecal coliform for 2005 at the DEQ GW Parkway Station

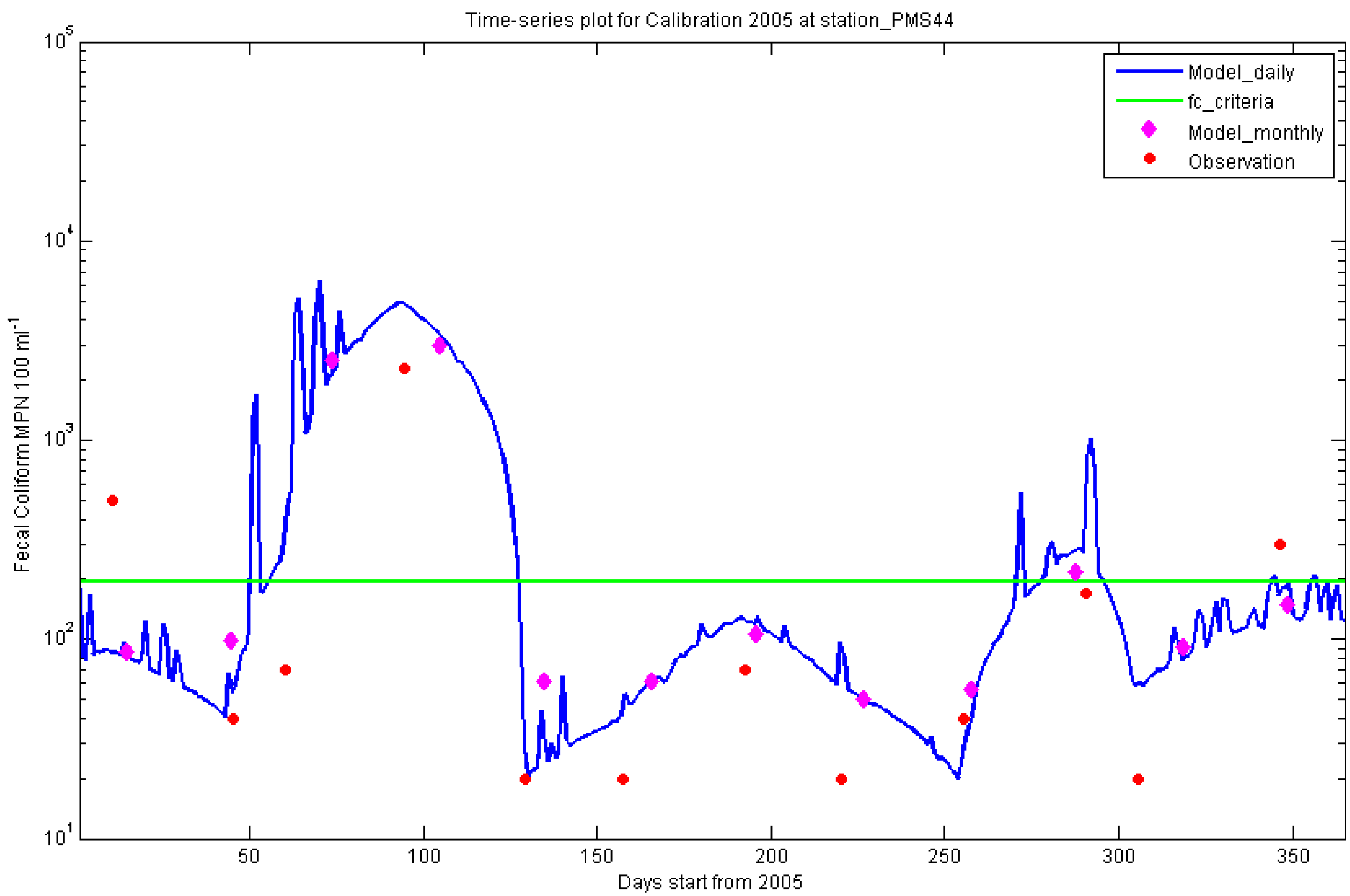


Figure 4-52: Time series of observed and modeled fecal coliform for 2005 at PMS44

Additional Remarks on ELCIRC Bacteria Calibration

The effect of the Chezy coefficient on the water level is relatively straightforward. The sensitivity of the decay rate's effect on the variation of fecal coliform concentration, however, can be further clarified by an analysis of the analytical solution of the advection-dispersion equation and its application to Hunting Creek.

Consider a system in which physical transport is primarily one dimensional; i.e., solute concentrations are laterally and vertically well mixed so that concentrations vary only in the longitudinal or downstream direction. In addition, a steady, uniform flow field is imposed and the effects of dispersion are spatially constant. Finally, assume that biogeochemical processes may be described in terms of first-order reactions wherein the transformation rate is proportional to the solute concentration. Given these assumptions, conservation of mass yields the constant-parameter advection-dispersion equation with first-order decay (e.g., Runkel and Bencala, 1995):

$$\frac{\partial C}{\partial t} = -U\frac{\partial C}{\partial x} + D\frac{\partial^2 C}{\partial x^2} - \lambda C \qquad \text{(`1)}$$

where C = concentration [ML^{-3}]; t = time [T]; U = flow velocity [LT^{-1}]; x = distance [L]; D = dispersion coefficient [$L^2 T^{-1}$]; and λ = first-order rate coefficient [T^{-1}].

The analytical solutions may be found in the literature for the case of a continuous source with initial and boundary conditions given by:

$$C(x, 0) = 0 \qquad \text{for } x \geq 0$$

$$C(0, t) = C_0 \qquad \text{for } t \geq 0$$

$$C(\infty, t) = 0 \qquad \text{for } t \geq 0 \qquad (2)$$

where C_0 = concentration at the upstream boundary [ML^{-3}].

For the case of conservative solutes (λ= 0), the analytical solution is given by (Ogata and Banks, 1961):

$$C(x,t) = \frac{C_0}{2}\left[erfc\left(\frac{x-Ut}{2\sqrt{Dt}}\right) + exp\left(\frac{Ux}{D}\right)erfc\left(\frac{x+Ut}{2\sqrt{Dt}}\right)\right] \quad (3)$$

(A) (B) (C)

The analytical solution for non-conservative solutes ($\lambda \neq 0$) is presented by Bear (1972, p. 630) and developed using Laplace transforms by O'Loughlin and Bowmer (1975):

$$C(x,t) = \frac{C_0}{2}\left[exp\left\{\frac{Ux}{2D}(1-\Gamma)\right\} erfc\left(\frac{x-Ut\Gamma}{2\sqrt{Dt}}\right) + exp\left\{\frac{Ux}{2D}(1+\Gamma)\right\} erfc\left(\frac{x+Ut\Gamma}{2\sqrt{Dt}}\right)\right]$$

(4)

(D)' (A)' (B)' (C)'

where

$$\Gamma = \sqrt{1+2H} \quad (5)$$

$$H = \frac{2\lambda D}{U^2} \quad (6)$$

In comparing (3) and (4), the contribution of the first order decay constant λ to the solution of equation (1) was recognized by the two parameters Γ and H. When $\lambda = 0$, H becomes 0 and $\Gamma = 1$, equation (4) degenerates to equation (3), which is the solution for the conservative concentration [for term (D)' in (4) become 1; Term (A)' in (4) become term (A) in (3); Term (B)' in (4) become term (B) in (3); Term (C)' in (4) become term (C) in (3)].

From this comparison, the contribution of the first order decay rate λ is scaled by $2\,D/U^2$. In other words, the effect of decay rate on the concentration depends on magnitude of D and U^2. For example, if U is very large, then the concentration change will be less sensitive to the decay rate λ for small H; or vice versa, if U is small, then H is large, the concentration change will be much more sensitive to the decay rate λ.

The majority of the monitoring stations used in calibrating the Hunting Creek ELCIRC Model are located in the Hunting Creek embayment where it is very shallow, and broad expanses of mudflats are exposed during low tide (Limo-Tech 2008). The widespread presence of wetlands and marshy areas, as well as the wetting-and-drying during the tidal cycle, make the velocities very low in the system, as shown by the velocity vectors in **Figure 4-53**. Because of the low velocity in the embayment, it can be expected that the fecal coliform concentration will be sensitive to the decay rate λ. Furthermore, the calibrated value of decay rate λ under low flow conditions should be expected to be towards the low end of values reported in the literature.

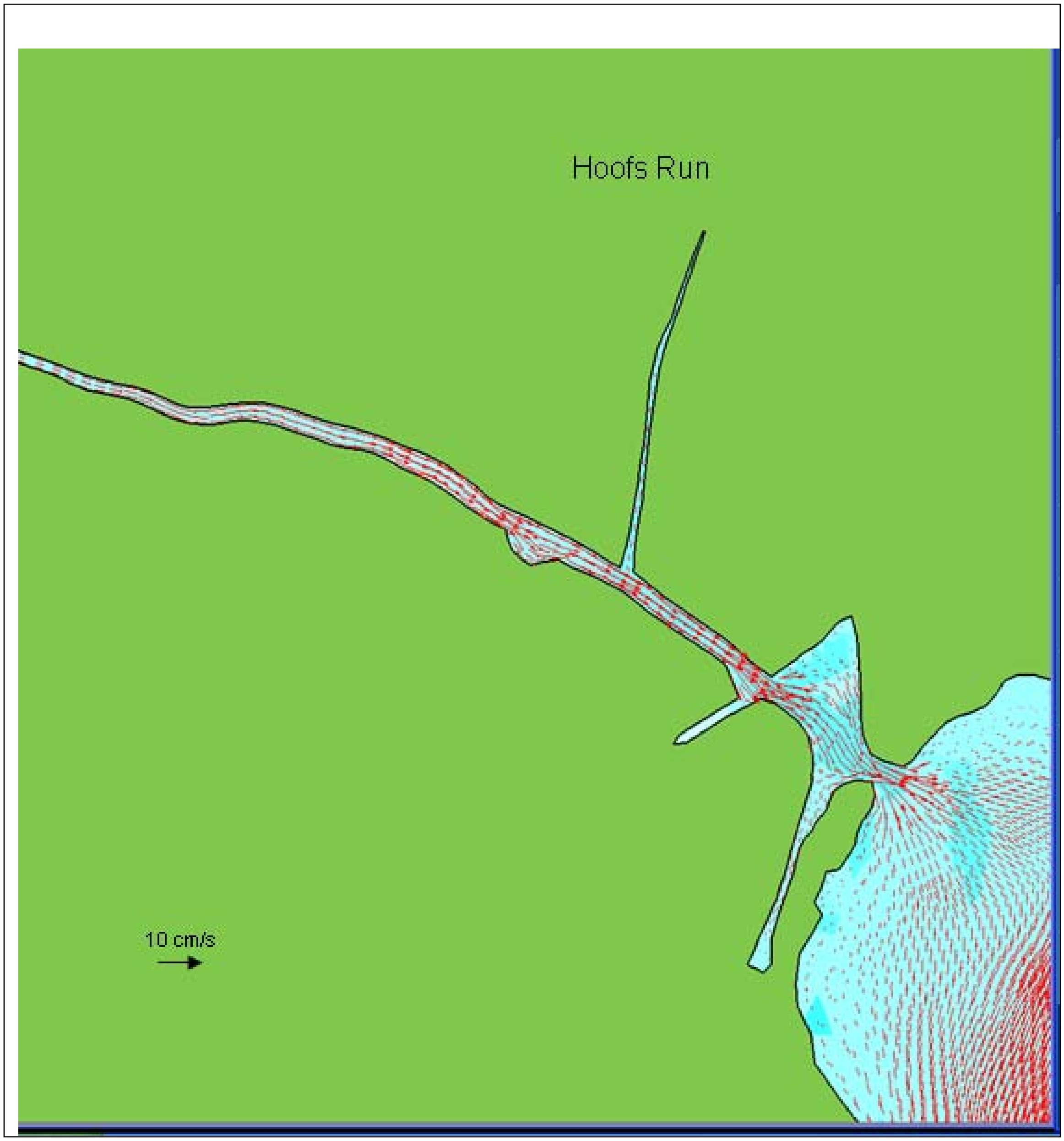


Figure 4-53: Spatial distribution of tidal velocity during maximum ebb in the Hunting Creek, Hunting Creek embayment, and portion of Potomac River

5 Allocation

Allocation analysis was the third stage in the development of the Holmes Run, Cameron Run, and Hunting Creek bacteria TMDLs. The purpose of this third stage was to develop the framework for reducing bacteria loading under the existing watershed conditions so that water quality standards can be met. The TMDL represents the maximum amount of a pollutant that the stream can receive without exceeding the water quality criteria. The load allocations for the selected scenarios were calculated using the following equation:

$$TMDL = \sum WLA + \sum LA + MOS$$

Where:

WLA = waste load allocation (point source contributions)
LA = load allocation (non-point source allocation)
MOS = margin of safety

Typically, several potential allocation strategies would achieve the TMDL endpoint and water quality criteria. Available control options depend on the number, location, and character of pollutant sources.

5.1 Incorporation of Margin of Safety

The margin of safety (MOS) is a required component of the TMDL to account for any lack of knowledge concerning the relationship between effluent limitations and water quality. According to EPA guidance (*Guidance for Water Quality-Based Decisions: The TMDL Process, 1991*), the MOS can be incorporated into the TMDL by using one of the following methods:

- implicitly incorporating the MOS using conservative model assumptions to develop allocations
- explicitly specifying a portion of the TMDL as the MOS and using the remainder for allocations

The bacteria TMDLs for Holmes Run, Cameron Run, and Hunting Creek use an implicit MOS. The MOS was implicitly incorporated into these TMDLs by using conservative estimates for all known factors that would affect bacteria loadings in the watershed, consistent with the observed bacteria concentrations. These factors include animal populations and their bacteria production rates, as well as model parameters such as decay rates. By using conservative estimates, these factors describe the worst-case scenario under which the highest bacteria concentrations would occur in Holmes Run, Cameron Run, or Hunting Creek.

In tidal Hunting Creek, two additional conservative assumptions were made. First, the concentration of the source responsible for the largest volume of water entering tidal Hunting Creek, ASA's WWTP, was set at the fecal coliform equivalent of its monthly *E. coli* permit limit, 126 cfu/100 ml, which is also the geometric mean water quality criterion. Second, as will be explained in more detail in Section 5.2.2, TMDL scenarios for tidal Hunting Creek were developed based on the principle that the tidal drainage to Hunting Creek had to meet water quality standards without significant dilution from the Potomac River. Potential TMDL scenarios assumed that water quality standards were met by sources outside of Hunting Creek at their point of discharge. For all potential TMDL scenarios, the concentrations at the boundaries of the model domain in the Potomac River were held at the fecal coliform equivalent of the *E. coli* geometric mean standard of 126 cfu/100 ml (195 cfu/100 ml fecal coliform equivalent). Additionally, TMDL scenarios set all sources within the model domain, but outside of the Hunting Creek watershed, at a constant fecal coliform concentration of 195 cfu/100 ml.

By implicitly incorporating the MOS, these TMDLs are ensured to meet the monthly *E. coli* geometric mean standard of 126 cfu/ 100 ml with 0% exceedance if the TMDL plan is followed.

5.2 Allocation Scenario Development

This section discusses the development of potential TMDL scenarios for the non-tidal Holmes Run and Cameron Run segments (Section 5.2.1) and for the tidal Hunting Creek (Section 5.2.2) segment. A TMDL Scenario that meets water quality standards in each impaired segment was determined, and the *E. coli* loading rates associated with the TMDL Scenario were identified by land use (Section 5.2.3). The WLAs for permitted point sources (including MS4s) are presented in Section 5.3.3. Finally, the method for determining the daily expression of the TMDL and its allocations is discussed (Section 5.2.4).

5.2.1 Allocation Scenario Development for Holmes Run and Cameron Run

The calibrated Cameron Run HSPF Model was used to simulate potential TMDL Scenarios for the non-tidal watershed. Each scenario is characterized by specifying a reduction of bacteria loads from sources. Three categories of sources were considered: (1) human sources, which in the non-tidal watershed include failing septic systems and sanitary sewer overflows (SSOs); (2) direct deposition into streams by wildlife; and (3) edge-of-stream (EOS) bacteria loads transported from the landscape in runoff, interflow, and groundwater discharge.

Failing septic systems and SSOs are not authorized discharges; therefore, the bacteria loads from these sources were eliminated in every potential TMDL Scenario. Operationally, this was implemented by eliminating their contribution to the simulated surface bacteria loading rates in the HSPF model. Thus a potential TMDL scenario can be defined by its level of reduction of direct deposition by wildlife and by the reduction in the EOS loads required to meet water quality standards. The latter was implemented by a percent reduction in the simulated load from the PERLND or IMPLND segment which is input into the corresponding river segment. **Table 5-1** shows reduction rates for the four potential TMDL scenarios.

Potential TMDL scenarios were run for the two-year simulation period of 2004-2005. This period includes representative low and high flow conditions but excludes the record low flow (2002) and high flow (2003) years of the calibration. Potential TMDL scenarios were assessed by determining the simulated rate of exceedance of the calendar month geometric mean criteria for *E. coli* bacteria. Since the Cameron Run HSPF Model simulates fecal coliform bacteria, the daily average simulated fecal coliform bacteria concentrations were converted to *E. coli* concentrations using the VADEQ translator equation.

Table 5-1 also shows the frequency of exceedances of the monthly geometric mean *E. coli* water quality criterion.

Table 5-1: Definition of Potential Non-tidal TMDL Scenarios and Exceedance Rates					
Scenario	**Reduction in Human Sources**	**Reduction in Wildlife Direct Deposition**	**Reduction in Edge of Stream Load**	**Holmes Run Exceedance Rate**	**Cameron Run Exceedance Rate**
Base	0%	0%	0%	54.2%	66.7%
0-NT	100%	0%	0%	54.2%	66.7%
1-NT	100%	0%	100%	0%	0%
2-NT	100%	100%	0%	16.7%	12.5%
3-NT	100%	50%	75%	4.2%	4.2%
4-NT	100%	50%	83%	0%	0%

The impact of a reduction in human sources is almost negligible. A 100% reduction in EOS loads meets bacteria water quality standards but a 100% reduction in direct deposition of bacteria by wildlife does not. Water quality standards are met by Scenario 4-NT, which calls for an 83% reduction in EOS loads and a 50% reduction in direct deposition by wildlife.

5.2.2 Allocation Scenario Development for Hunting Creek

The calibrated Hunting Creek ELCIRC Model was used to simulate potential TMDL scenarios for tidal Hunting Creek. Potential TMDL scenarios are defined by setting bacteria loads from (1) non-tidal Cameron Run; (2) smaller tributaries and direct drainage to tidal Hunting Creek; (3) ASA WWTP; and (4) COA CSS. TMDL Scenarios also require determining the boundary conditions at the downstream boundary of the impairment at the confluence of Hunting Creek and the Potomac River.

Non-Tidal Cameron Run

Bacteria loads from non-tidal Cameron Run were simulated using the calibrated Cameron Run HSPF Model. Under each potential tidal TMDL scenario, reductions in sources in non-tidal Cameron Run were specified according the three categories used for the non-tidal TMDLs: (1) human sources, (2) direct deposition by wildlife; and (3) EOS loads. Since water quality standards must be met in non-tidal Cameron Run, the TMDL condition determined in the upstream watershed was selected to represent non-tidal flows and bacteria loads in the tidal domain.

Small Tributaries and Direct Drainage to Cameron Run/Hunting Creek

Bacteria loads from smaller tributaries, such as Hooff Run, Quander Creek, or Taylor Run, and direct drainage to tidal waters were simulated using bacteria loads from segment 90 and segments 110-190 of the calibrated Cameron Run HSPF Model. Under each potential tidal TMDL scenario, reductions in sources in small tributaries and direct drainage to tidal Cameron Run/Hunting Creek were specified according the three categories used for the non-tidal TMDLs: (1) human sources, (2) direct deposition by wildlife; and (3) EOS loads. Different levels of reduction were applied to (A) Hooff Run and modeling segments parameterized according to Hooff Run, Segments 110, 130, 150, and 190; and (B) segments 120, 140, and 160-180, which are parameterized according to Segment 100. As described in Section 4.2.1, COA monitoring data indicates that bacteria concentrations in non-tidal Hooff Run, above the CSO outfalls, are much higher than those observed in the rest of the watershed. Segment 90, the HSPF segment representing non-tidal Hooff Run, was calibrated accordingly, and the resulting parameterization was applied to Segments 110, 130, 150, and 190, which represent the City of Alexandria downstream of Telegraph Road. Although Hooff Run is not listed as impaired in the 2008 Integrated Report for a bacteria impairment, analysis using the Cameron Run HSPF Model indicates that the *E. coli* geometric mean criterion could not be met in Hooff Run without the equivalent of (1) 100% reduction in human sources; (2) a 50% reduction in direct deposition by wildlife; and (3) a 98% reduction in EOS loads. The resulting loads were considered the minimum necessary for the Hunting Creek Bacteria TMDL. Reductions in loads from Segments 120, 140, and 160-180 were set at the same level as reductions for non-tidal Cameron Run.

ASA Advanced Wastewater Treatment Plant

Under all potential TMDL Scenarios, loads from the ASA Advanced Wastewater Treatment Plant were set assuming (1) a fecal coliform concentration, 195 cfu/100 ml, equivalent to the permitted *E. coli* concentration of 126 cfu/ 100 ml; and (2) a daily flow of 66 MGD, which represents the plant's design capacity of 54 MGD with an additional 12 MGD allotted for the future expansion and growth of point sources in the watershed.

COA Combined Sewer System

Under potential TMDL Scenarios for Hunting Creek, reductions were made to CSS bacteria loads by outfall for Outfalls 002, 003, and 004. Outfall 001 discharges to the Potomac River and is not given an allocation under this TMDL. Reductions in CSO bacteria loads were simulated by keeping the simulated bacteria concentration at the outfall's baseline level, but proportionately reducing flows on each day an overflow occurs. In other words, a 50% reduction in CSO loads was implemented by reducing flows by 50% for each overflow event.

Boundary Conditions

For bacteria TMDLs completed in Virginia, it is VADEQ's standard practice to assume:

1. Bacteria concentrations at an upstream or downstream boundary of an impaired segment are meeting water quality standards for bacteria.

2. Bacteria concentrations at the upstream or downstream boundary are not providing a source of dilution that would increase the assimilative capacity of an impaired segment.

In other words, the sources within the impaired segment must provide the reductions necessary to meet water quality standards in the impaired segment by themselves, without assistance from sources outside of the impaired segment. In this way the boundaries are neutral with respect to the level of reduction of bacteria sources within a segment necessary to meet standards. This is particularly important in the case of Hunting Creek, where the boundary of the impaired segment is the state border between Maryland and Virginia. To assume point and non-point source bacteria concentrations at their point of discharge are below the water quality standards of the other jurisdictions could be equivalent to requiring those sources in Maryland or the District of Columbia to reduce their bacteria loading rates below the levels required to meet their own standards, in order to provide assimilative capacity for Virginia sources.

In other Virginia bacteria TMDLs, setting boundary concentrations at water quality standards was achieved by setting the segment boundary at the *E. coli* geometric mean criterion of 126 cfu/ 100 ml, or, in most cases, the fecal coliform concentration equivalent to the *E. coli* standard, 195 cfu /100 ml (VADEQ, 2008b; VADEQ, 2010). In the Hunting Creek

ELCIRC Model, however, the model domain deliberately does not coincide with the boundary of the impaired segment. To simulate the exchange between Hunting Creek and the Potomac River, the model domain was extended beyond the Hunting Creek impairment to include a portion of the Potomac River in Maryland and the District of Columbia. The discussion below describes the approach used to establish the model boundaries:

1. The concentrations at the model domain boundary on the Potomac River at DCDOE monitoring stations PMS37 and PMS55 were set at a constant value of 195 cfu/ 100 ml. Potomac River flows were represented as actual flows during the model simulation period 2004 and 2005.

2. The concentrations of all input sources in the extended Potomac domain (e.g. those sources within the model domain but outside of the Hunting Creek watershed) were set at a constant concentration of 195 cfu/ 100 ml at their point of discharge. These sources include: (1) Blue Plains outfalls 001 and 002; (2) COA CSO outfall 001; (3) direct drainage from portions of Virginia outside of the Hunting Creek impairment (Segments 210 and 220); (4) direct drainage from DC (Segment 230) and Maryland (250); (5)and Oxon Run (Segment 240)) . Flows from all sources were represented as actual flows during the model period for point source discharges (e.g. Blue Plains, CSO outfall 001) and modeled HSPF flows for the remaining model segments.

3. The decay rate in the Potomac River was set at 0.1 /day consistent with model calibration. Alternative scenarios such as applying a bacteria decay rate of 0.0/day for the mainstem of the Potomac River while maintaining the decay rate of 0.1/day in the Hunting Creek watershed as established in model calibration were also considered.

The bacteria decay rate of 0.0/day was applied to evaluate reduction requirements needed when the effective water column concentration of bacteria at the boundary of the impaired segment was fixed at the water quality standard of 126 cfu/100 ml *E.* coli (translated to 195 cfu/ml fecal coliform).

Tidal Hunting Creek TMDL Scenario Definitions

In all potential TMDL scenarios simulated for Hunting Creek, the ASA WWTP loading rate was fixed at its permitted concentration and a design flow of 66 MGD. Both Cameron Run, as well as the small tributaries and direct drainage to tidal Hunting Creek, were given the reductions that allowed bacteria water quality standards to be met in non-tidal Cameron Run and Hooff Run. Thus, the effective differences between potential TMDL scenarios in tidal Hunting Creek are due differences in levels of reductions applied to CSO outfalls 002, 003, and 004. **Table 5-2** shows the reductions applied under each potential TMDL scenario

Application of the Geometric Mean *E. Coli* Criterion in Tidal Waters

Potential TMDL scenarios were assessed by determining the simulated exceedance rate of the calendar month geometric mean criterion for *E. coli* bacteria. It is standard practice in Virginia bacteria TMDLs to use the simulated daily average concentration to calculate the monthly geometric mean concentration. It is apparent, however, that the cell size of the ELCIRC model is small compared to the size of the impairment, which itself occupies only a about a half of a square mile. Tidal waters are of course subject to ebb and flood of the tidal cycle twice over the daily averaging period. Simulated particle tracking using the Hunting Creek ELCIRC model indicates that a particle released at CSO Outfall 002 traverses the Hunting Creek embayment in the course of an average single tidal cycle.

For these reasons, the Hunting Creek impairment was divided into two assessment areas, one upstream of the George Washington Memorial Parkway (GW Parkway) and one downstream from the GW Parkway, occupying the Hunting Creek embayment adjacent to the Potomac River. The former will be referred to as "Upstream Hunting Creek," the latter as the "Hunting Creek Embayment." Upstream Hunting Creek behaves primarily as a tidal river, whereas the Hunting Creek Embayment is subject to more complicated circulation patterns under the influence of the Potomac River.

A monthly geometric mean *E. coli* concentration for each assessment area was calculated as an average of the simulated bacteria concentrations over each assessment area. More precisely, the following procedure was used to calculate the monthly geometric mean *E. coli* concentration for an assessment area:

1. The daily average simulated fecal coliform concentration for each node in an assessment area was calculated as the arithmetical average of simulated hourly fecal concentration output by the ELCIRC model.

2. The daily average simulated fecal coliform concentration for each assessment unit was calculated as the arithmetical average of the simulated nodal bacteria concentrations.

3. The daily average fecal concentration for each assessment unit was converted to a daily average *E. coli* concentration using the VADEQ translator equation.

4. The geometric means of the daily average *E. coli* concentrations were calculated on a calendar-month basis from the daily average concentrations for each assessment unit.

The resulting simulated geometric mean *E coli* concentrations were then compared to the 126 cfu/100 ml geometric mean criterion for *E. coli* bacteria to determine if water quality standards for bacteria were met.

Results of the Simulation of Potential TMDL Scenarios for Hunting Creek

Table 5-2 shows the percent exceedance rates for each potential TMDL scenario in the Hunting Creek embayment assessment areas. The exceedance rate is the percent of the months in the two-year TMDL simulation period, 2004-2005, which do not meet the monthly geometric mean criterion. In Scenarios 3-T through 10-T different reductions were applied to CSO Outfall 002, compared to CSO Outfalls 003 and 004, because of the relative influence the outfalls have on the assessment areas in which they are located.

Scenarios 1-T through 5-T set the boundary at the confluence of Hunting Creek and Potomac River to approximately 195 cfu/ 100 ml by setting the bacteria decay rate in the Potomac River to zero. Among the scenarios which set the impairment boundary at the water quality standard, only Scenario 5-T meets the monthly geometric mean criterion. Scenario 5-T calls for an 85% reduction in bacteria loads from CSO Outfall 002 and a 99% reduction in bacteria loads from CSO Outfalls 003 and 004.

Scenarios 6-T through 10-T allow for bacteria decay in the Potomac River at the calibrated decay rate of 0.1/day. As explained in Section 5.2.2, this approach provides for all sources within the model domain, including those in different jurisdictions, to meet water quality standards at the point of discharge. CSO Outfalls 003 and 004 were set at the 99% reduction as in Scenario 5-T; only the reduction rate for CSO Outfall 002 varied between scenarios. Based on previous modeling runs, it was anticipated that applying the decay rate in the Potomac River might allow larger bacteria loads to be discharged from CSO 002, but that increasing loads from outfall 002 tended to increase concentrations in Upstream Hunting Creek.

Of the five scenarios which used a decay rate of 0.1/ day in the Potomac River, only Scenario 10-T met the monthly geometric mean *E. coli* criterion. The reduction required under Scenario 10-T for CSO Outfall 002 is 80%, as compared to an 85% reduction required when a 0.0/day decay rate is fixed for the Potomac River outside of the Hunting Creek watershed.

Scenario 10-T was used as the basis for the TMDL for Hunting Creek. Both scenarios do not assume reductions from sources outside of Hunting Creek in excess of those required to meet water quality standards in the Potomac River.

In addition to the TMDL Scenario Runs that were done for Hunting Creek, five other model scenario runs (labeled as "Sensitivity Runs") were performed to evaluate the relative impact of various sources of bacteria in the watershed. These sensitivity runs, as well as additional details on the TMDL Scenario Runs, can be found in Appendix D and Appendix C, respectively.

Table 5-2: Potential Tidal TMDL Scenario Definitions, Load Reductions, and Exceedance Rates

Scenario	Boundary	Reductions in Upstream Loads (Segment 100) and Direct Drainage (Segments 120, 140, 160-180)			Reductions in Hooff Run Loads (Segment 90) and Direct Drainage (Segments 110, 130, 150, and 190)			CSO Reductions		Exceedance Rate	
		Human	Direct Deposition Wildlife	EOS	Human	Direct Deposition Wildlife	EOS	002	003 and 004	Upstream Hunting Creek	Hunting Creek Embayment
1-T	0.0 Decay	100%	50%	83%	100%	50%	98%	0%	0%	62.4%	70.8%
2-T	0.0 Decay	100%	50%	83%	100%	50%	98%	95%	95%	4.2%	0%
3-T	0.0 Decay	100%	50%	83%	100%	50%	98%	75%	99%	0%	8.4%
4-T	0.0 Decay	100%	50%	83%	100%	50%	98%	50%	98%	4.2%	33.3%
5-T	0.0 Decay	100%	50%	83%	100%	50%	98%	85%	99%	0%	0%
6-T	0.1 Decay Rate	100%	50%	83%	100%	50%	98%	35%	99%	0%	33.3%
7-T	0.1 Decay Rate	100%	50%	83%	100%	50%	98%	50%	99%	0%	25.0%
8-T	0.1 Decay Rate	100%	50%	83%	100%	50%	98%	65%	99%	0%	8.3%
9-T	0.1 Decay Rate	100%	50%	83%	100%	50%	98%	75%	99%	0%	4.2%
10-T	0.1 Decay Rate	100%	50%	83%	100%	50%	98%	80%	99%	0%	0%

5.2.3 Average Annual E. coli Loads by Source

Fecal coliform input loads for each impaired segment were translated into *E. coli* load and wasteload allocations using the method described in Section 4.3. The TMDL was determined as the sum of all input loads, including: (1) direct deposition by wildlife; (2) land-based EOS loads; (3) ASA WWTP (Hunting Creek only); and (4) COA CSOs (Hunting Creek only). **Table 5-3** shows the average annual *E. coli* loads and the allocated loads by source, as given by Scenario 4-NT (Holmes Run and Cameron Run) and Scenario 5-T (Hunting Creek).

Table 5-3: Scenario 4-NT and Scenario 5-T Average Annual *E. coli* Loads By Source

Land Use	Holmes Run	Cameron Run	Hunting Creek
Open Space/Parks	5.49E+12	1.14E+13	1.25E+13
Wildlife Direct Deposition	3.50E+12	8.39E+12	9.84E+12
Total Non-Point Source (LA):	**8.99E+12**	**1.98E+13**	**2.23E+13**
Transportation	2.12E+13	3.41E+13	3.65E+13
Commercial	1.76E+13	2.65E+13	2.85E+13
Industrial	5.61E+11	4.93E+12	5.47E+12
Low Density Residential	8.26E+12	1.49E+13	1.55E+13
Medium Density Residential	2.79E+13	4.02E+13	4.35E+13
High Density Residential	8.29E+12	1.25E+13	1.51E+13
Total MS4 (WLA):	**8.38E+13**	**1.33E+14**	**1.45E+14**
ASA WWTP and Future Growth Allocation	N/A	N/A	1.15E+14
COA CSS	N/A	N/A	6.42E+13
Total VPDES Permitted Point Sources (WLA):	**N/A**	**N/A**	**1.79E+14**
Total:	**9.28E+13**	**1.53E+14**	**3.46E+14**

5.2.4 Calculation of the Daily Expression of TMDLs

The long-term average *E. coli* loads and coefficient of variations were determined to implement the final allocation scenarios and to express the TMDL on a daily basis. Assuming a log-normal distribution of data and a probability of occurrence of 95%, the maximum daily loads were determined using the following equation (*USEPA OWOW 2007 Options for Expressing Daily Loads in TMDLs*):

$$MDL = LTA \times Exp[z\sigma - 0.5\sigma^2]$$

where;

MDL = maximum daily limit (cfu/day)
LTA = long-term average (cfu/day)
z = z statistic of the probability of occurrence
$\sigma^2 = \ln(CV^2+1)$
CV = coefficient of variation

The following sections present the waste load allocation and load allocations for the impaired segments.

5.3 Wasteload Allocation

This section outlines the wasteload allocations (WLA) for the impaired segments. It presents the existing and allocated loads for each permitted (VPDES and MS4) facility contributing to the impaired segment. MS4 permittees are given WLAs under each of the three impairments. There are no individual VPDES permits in either the Holmes Run or Cameron Run watershed. Two facilities, ASA's Advanced Wastewater Treatment Plant and COA's Combined Sewer System, have individual VPDES permits authorizing discharge of bacteria to Hunting Creek.

5.3.1 Alexandria Sanitation Authority Advanced Wastewater Treatment Plant

ASA's Advanced Wastewater Treatment Plant is one of two facilities with individual VPDES permits authorizing discharge of bacteria to tidal Hunting Creek. As described in Section 5.2, it is given a wasteload allocation based on its *E. coli* permit limit of 126 cfu/100 ml and a daily average flow of 54 MGD. In addition, a waste load allocation for the future growth and expansion of point sources in the watershed is also included. This future growth allocation is equivalent to a daily average flow of 12 MGD and an *E. coli* concentration of 126 cfu/100mL. **Table 5-4** shows the ASA WWTP's wasteload allocation along with the future growth allocation.

Table 5-4: E. coli Wasteload Allocation for ASA Advanced Wastewater Treatment Plant

Permit Number	Permit Type	Design Flow (MGD)	Permit Concentration (cfu/100 ml)	Wasteload Allocation (cfu/year)
VA0025160	Municipal	54	126	9.40E+13
Allocation for the Future Growth of Point Sources:				2.10E+13
Total:				**1.15E+14**

5.3.2 City of Alexandria Combined Sewer System

Outfalls 002, 003, and 004 of the COA CSS were given WLAs based on the reductions required to meet the monthly geometric mean water quality criterion for *E. coli* bacteria under TMDL Scenario 5-T. Table 5-5 shows the average annual WLA and percent reduction required for each outfall, as well as the total WLA and reduction for the three outfalls. Outfall 001, which discharges to the Potomac River, is outside the scope of these TMDLs.

Table 5-5: Wasteload Allocation for COA Combined Sewer System			
Permit Number	**Outfall**	**Wasteload Allocation (cfu/year)**	**Percent Reduction (%)**
VA0087068	002	6.26E+13	80%
	003	7.68E+11	99%
	004	8.52E+11	99%
	Total	**6.42E+13**	**86%**

5.3.3 MS4 Allocation

As discussed earlier, loads associated with MS4 permits are considered part of the wasteload allocations. Seven MS4 permits have been issued in the Hunting Creek drainage, including Phase I permits for Arlington County and Fairfax County, and Phase II permits for the City of Alexandria, the City of Falls Church, Fairfax County Public Schools, VDOT, and the George Washington Memorial Parkway. Arlington County and the George Washington Memorial Parkway are only given wasteload allocations in the Hunting Creek Bacteria TMDL; the other five permittees were given allocations in all three TMDLs.

All land-based loadings except the loadings from the open space and public land use categories were allocated to the MS4s. Due to the spatial overlap between MS4 entities and the resulting uncertainty of the appropriate operator of the system, the MS4 loads are aggregated by jurisdiction (Arlington County, Fairfax County, the City of Alexandria, and the City of Falls Church) in the TMDL.

Tables 5-6, 5-7, and **5-8** show the aggregated wasteload allocation and the percent reduction from current loads for Holmes Run, Cameron Run, and Hunting Creek, respectively.

Table 5-6: *E. Coli* Wasteload Allocation for MS4 Permits for Holmes Run			
Permit Number	**MS4 Permit Holder**	**Wasteload Allocation (cfu/year)**	**Percent Reduction (%)**
VAR040057	City of Alexandria	2.40E+13	83%
VAR040062	VDOT		
VA0088587	Fairfax County	5.47E+13	83%
VAR040104	Fairfax County Public Schools		
VAR040062	VDOT		
VAR040065	City of Falls Church	5.12E+12	83%
VAR040062	VDOT		

Table 5-7: *E. Coli* Wasteload Allocation for MS4 Permits for Cameron Run			
Permit Number	**MS4 Permit Holder**	**Wasteload Allocation (cfu/year)**	**Percent Reduction (%)**
VAR040057	City of Alexandria	3.20E+13	83%
VAR040062	VDOT		
VA0088587	Fairfax County	9.60E+13	83%
VAR040104	Fairfax County Public Schools		
VAR040062	VDOT		
VAR040065	City of Falls Church	5.12E+12	83%
VAR040062	VDOT		

Table 5-8: *E. Coli* Wasteload Allocation for MS4 Permits for Hunting Creek			
Permit Number	**MS4 Permit Holder**	**Wasteload Allocation (cfu/year)**	**Percent Reduction (%)**
VA0088579	Arlington County	3.68E+11	98%
VAR040062	VDOT		
VAR040057	City of Alexandria	3.73E+13	92%
VAR040062	VDOT		
VAR040111	George Washington Memorial Parkway		
VA0088587	Fairfax County	1.02E+14	83%
VAR040104	Fairfax County Public Schools		
VAR040062	VDOT		
VAR040111	George Washington Memorial Parkway		
VAR040065	City of Falls Church	5.12E+12	83%
VAR040062	VDOT		

5.4 Load Allocation

The load allocation represents the land-based loads from the open space and public land use categories, as well as direct deposition of bacteria by wildlife. **Tables 5-9, 5-10, and 5-11** summarize the load allocation and percent reduction from current loads for Holmes Run, Cameron Run, and Hunting Creek, respectively.

Table 5-9: Holmes Run *E. Coli* Load Allocation	
Load Allocation (cfu/year)	**Percent Reduction (%)**
8.99 E+12	77%

Table 5-10: Cameron Run *E. Coli* Load Allocation	
Load Allocation (cfu/year)	**Percent Reduction (%)**
1.98 E+13	76%

Table 5-11: Hunting Creek *E. Coli* Load Allocation	
Load Allocation (cfu/year)	**Percent Reduction (%)**
2.23 E+13	78%

5.5 TMDL Allocation Summary

Sections 5.5.1, 5.5.2, and 5.5.3 summarize the bacteria TMDLs for Holmes Run, Cameron Run, and Hunting Creek, respectively.

5.5.1 Bacteria TMDL Allocation Summary for Holmes Run

The daily bacteria TMDL for Holmes Run is shown in **Table 5-12**. The average annual bacteria TMDL is shown in **Table 5-13**. **Figure 5-1** shows the calendar-month geometric mean *E. coli* concentrations under existing conditions and after the reductions specified in Scenario 4-NT, the TMDL Scenario, are applied. As shown by Figure 5-1, a 100% reduction in bacteria loads from failing septic systems and SSOs, a 50% reduction in direct deposition by wildlife, and a 83% reduction in land-based edge-of-stream (EOS) loads results in bacteria concentrations that are below the geometric mean standard for *E. coli.*

Table 5-12: Holmes Run TMDL (cfu/day) for *E. coli* Bacteria

WLA	LA	MOS	TMDL
2.56E+11	2.74E+10	Implicit	2.83E+11

Table 5-13: Holmes Run TMDL (cfu/year) for *E. coli* Bacteria

WLA	LA	MOS	TMDL
8.38E+13	8.99 E+12	Implicit	9.28E+13

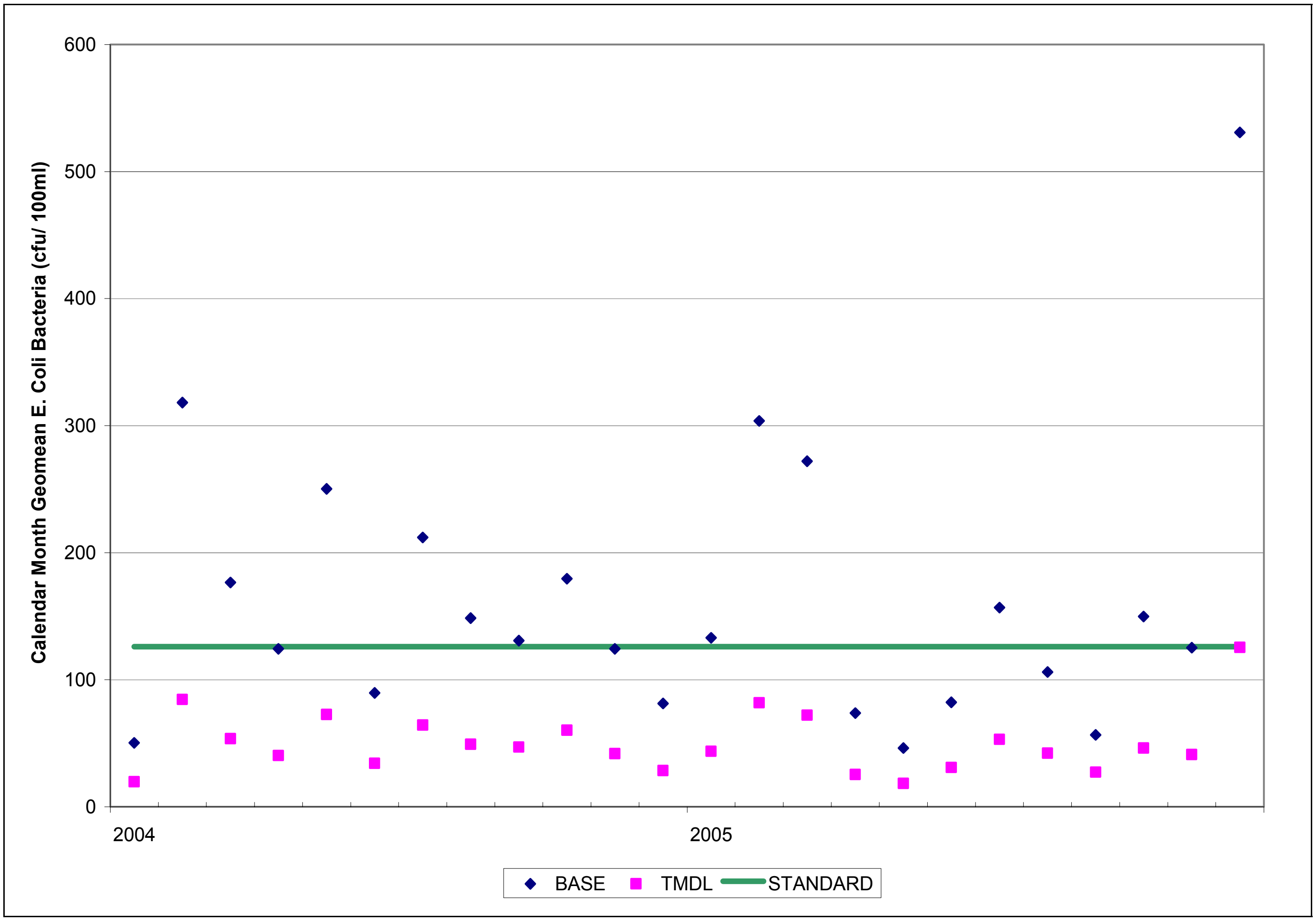


Figure 5-1: Holmes Run Calendar-Month Geometric Mean E. Coli Bacteria Concentrations (cfu/ 100 ml) under Existing Conditions and TMDL Scenario

5.5.2 Bacteria TMDL Allocation Summary for Cameron Run

The daily bacteria TMDL for Cameron Run is shown in **Table 5-14**. The average annual bacteria TMDL is shown in **Table 5-15**. **Figure 5-2** shows the calendar-month geometric mean *E. coli* concentrations under existing conditions and after the reductions specified in Scenario 4-NT, the TMDL Scenario, are applied. As shown by Figure 5-2, a 100% reduction in bacteria loads from failing septic systems and SSOs, a 50% reduction in direct deposition by wildlife, and a 83% reduction in land-based EPS loads results in bacteria concentrations that are below the geometric mean standard for *E. coli.*

Table 5-14: Cameron Run TMDL (cfu/day) for *E. coli* Bacteria

WLA	LA	MOS	TMDL
4.40E+11	6.54E+10	Implicit	5.05E+11

Table 5-15: Cameron Run TMDL (cfu/year) for *E. coli* Bacteria			
WLA	**LA**	**MOS**	**TMDL**
1.33E+14	1.98 E+13	Implicit	1.53E+14

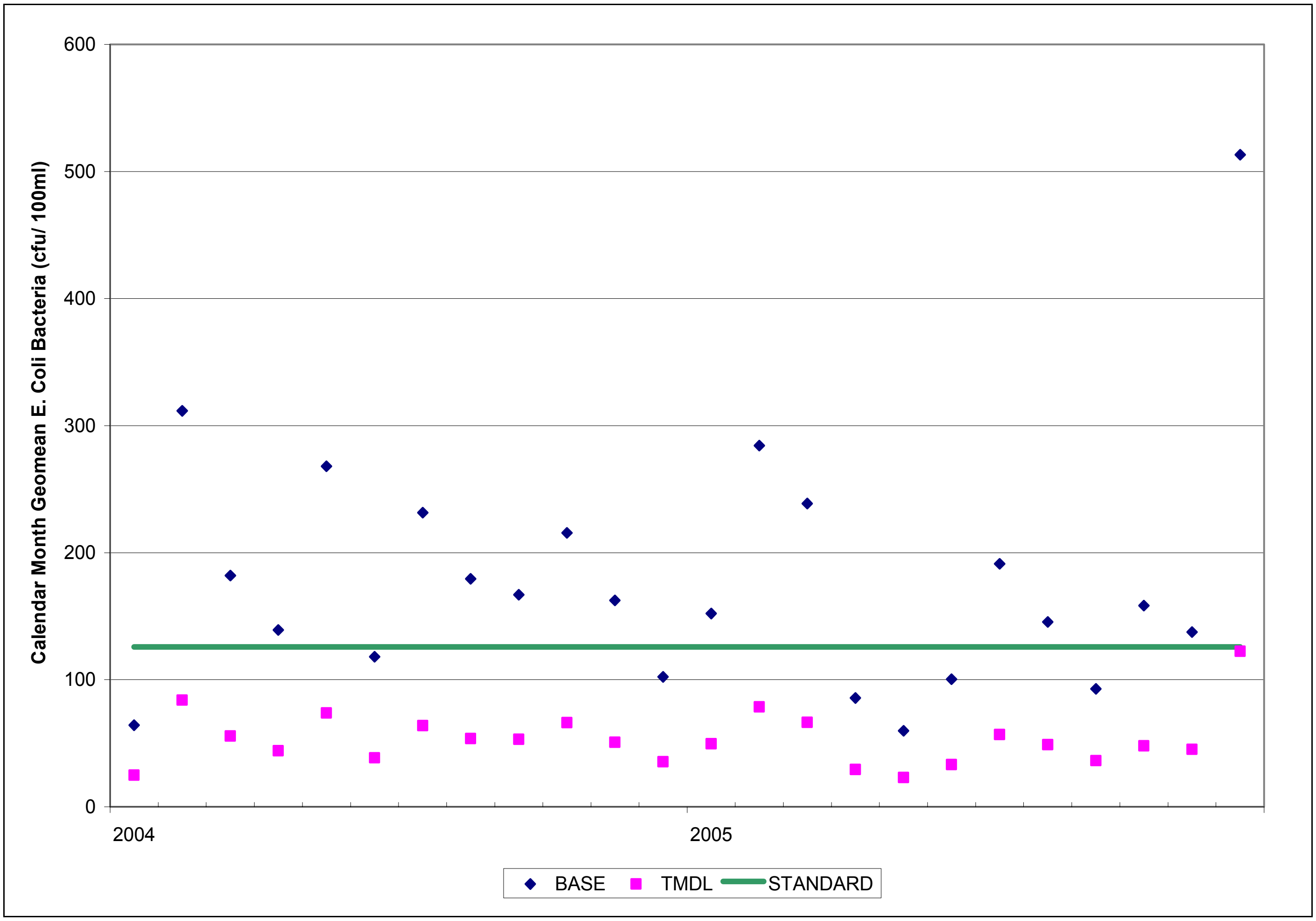


Figure 5-2: Cameron Run Calendar-Month Geometric Mean E. Coli Bacteria Concentrations (cfu/ 100 ml) under Existing Conditions and TMDL Scenario

5.5.3 Bacteria TMDL Allocation Summary for Hunting Creek

The daily bacteria TMDL for Hunting Creek is shown in **Table 5-16**. The average annual bacteria TMDL is shown in **Table 5-17**.

Figures 5-3 and **5-4** show the calendar-month geometric mean *E. coli* concentrations under existing conditions and after the reductions specified in Scenario 10-T, the TMDL Scenario, are applied in the Hunting Creek embayment assessment areas. As described earlier, attainment of the water quality standards is determined by aggregating the model outputs into two assessment areas identified as "Upstream Hunting Creek" and "Hunting Creek Embayment". As shown by Figures **5-3** and **5-4,** the following reductions in sources results in bacteria concentrations that are below the geometric mean standard for *E. coli*:

- 100 % reduction in bacteria loads from failing septic systems and SSOs
- 50% reduction in bacteria directly deposited by wildlife
- 83% reduction in land-based EOS loads from non-tidal Cameron Run and Segments 120, 140, 160, 170, and 180
- 98% reduction in land-based EOS loads from Segments 90, 110, 130, 150 and 190
- 80% reduction in bacteria loads from CSO Outfall 002
- 99% reduction in bacteria loads from CSO Outfalls 003 and 004

Table 5-16: Hunting Creek TMDL (cfu/day) for *E. coli* Bacteria

WLA	LA	MOS	TMDL
2.09E+12	1.90E+11	Implicit	2.28E+12

Table 5-17: Hunting Creek TMDL (cfu/year) for *E. coli* Bacteria

WLA	LA	MOS	TMDL
3.24E+14	2.23 E+13	Implicit	3.46E+14

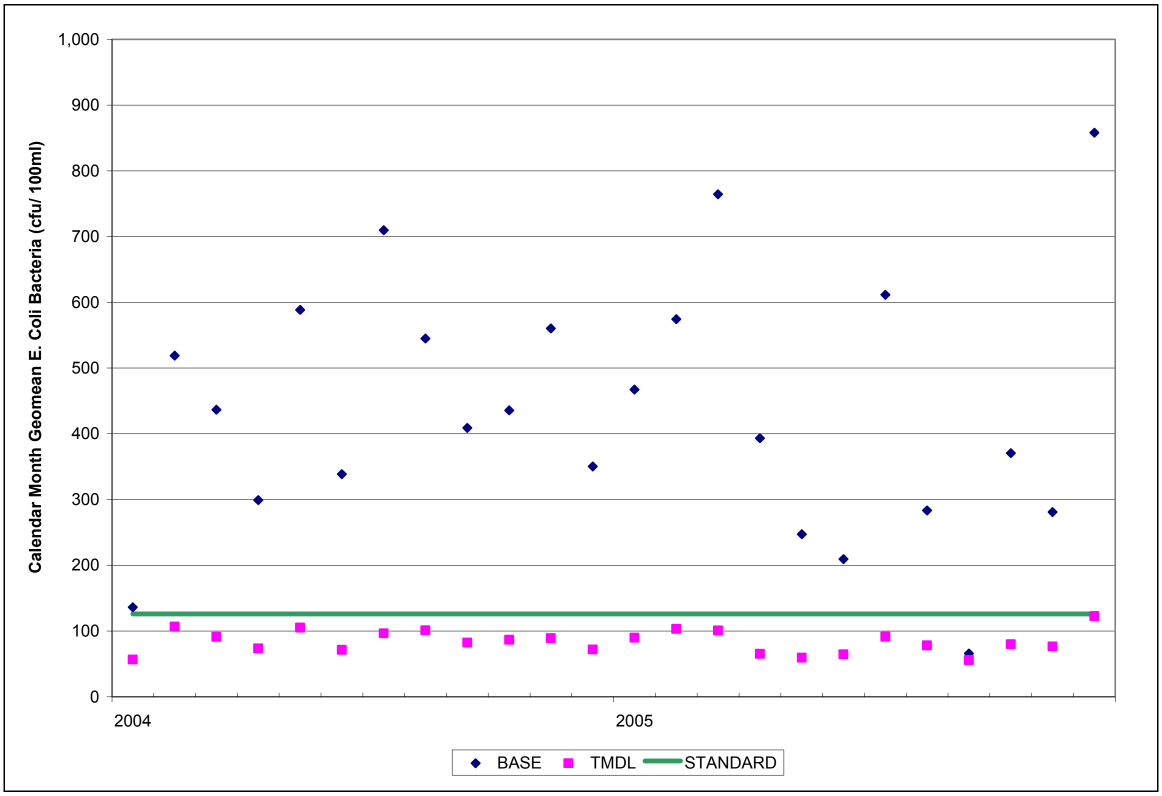


Figure 5-3: Upstream Hunting Creek Assessment Area - Calendar-Month Geometric Mean E. Coli Bacteria Concentrations (cfu/ 100 ml) under Existing Conditions and TMDL Scenario

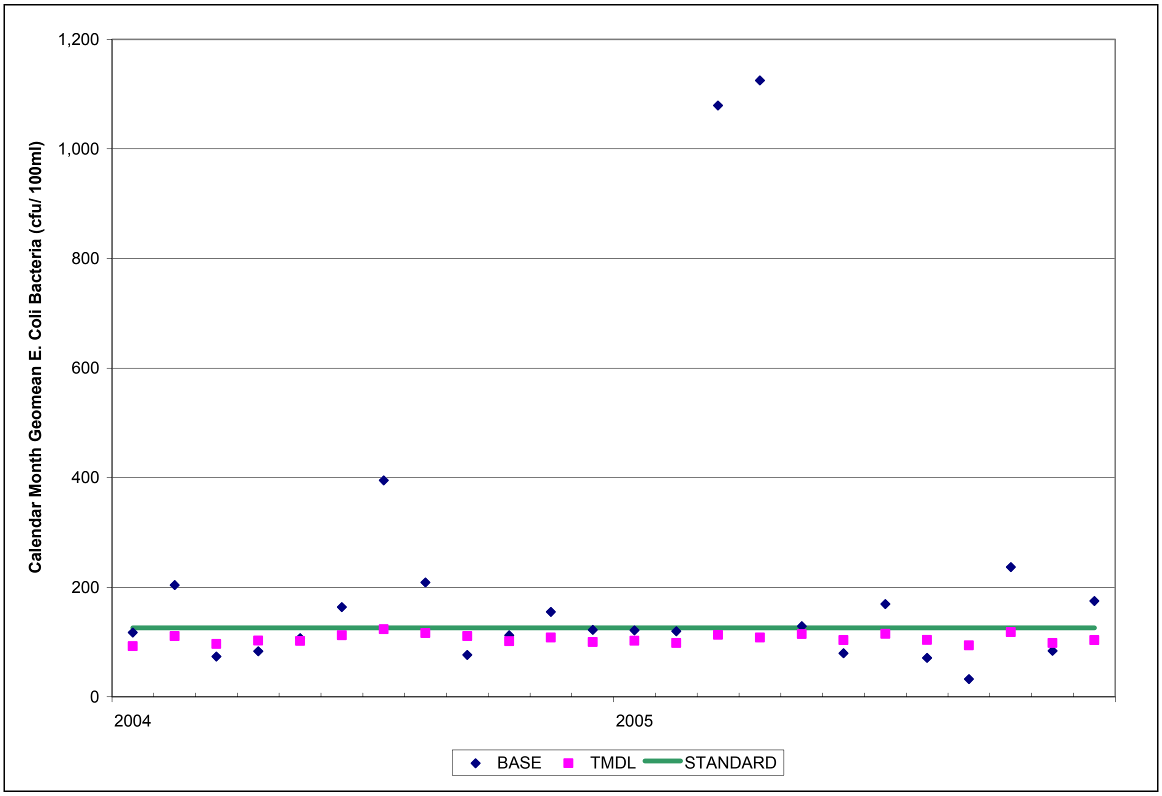


Figure 5-4: Hunting Creek Embayment Assessment Area - Calendar-Month Geometric Mean E. Coli Bacteria Concentrations (cfu/ 100 ml) under Existing Conditions and TMDL Scenario

6 TMDL Implementation

Once a TMDL has been approved by EPA, measures must be taken to reduce pollution levels from both point and non-point sources. The following sections outline the framework used in Virginia to provide reasonable assurance that the required pollutant reductions can be achieved.

6.1 Continuing Planning Process and Water Quality Management Planning

As part of the Continuing Planning Process, VADEQ staff will present both EPA-approved TMDLs and TMDL implementation plans to the State Water Control Board (SWCB) for inclusion in the appropriate Water Quality Management Plan (WQMP), in accordance with the Clean Water Act's Section 303(e) and Virginia's Public Participation Guidelines for Water Quality Management Planning.

VADEQ staff will also request that the SWCB adopt TMDL WLAs as part of the Water Quality Management Planning Regulation (9VAC 25-720), except in those cases when permit limitations are equivalent to numeric criteria contained in the Virginia Water Quality Standards, such as in the case for bacteria discharges resulting from treatment of municipal and industrial wastewater. This regulatory action is in accordance with §2.2-4006A.4.c and §2.2-4006B of the Code of Virginia. SWCB actions relating to water quality management planning are described in the public participation guidelines referenced above and can be found on VADEQ's web site under http://www.deq.state.va.us/tmdl/pdf/ppp.pdf. .

6.2 Staged Implementation

In general, Virginia intends for the required control actions, including Best Management Practices (BMPs), to be implemented in an iterative process that first addresses those sources with the largest impact on water quality. The iterative implementation of pollution control actions in the watershed has several benefits:

1. Enables tracking of water quality improvements following implementation through follow-up stream monitoring.
2. Provides a measure of quality control, given the uncertainties inherent in computer simulation modeling.

3. Provides a mechanism for developing public support through periodic updates on implementation levels and water quality improvements.
4. Helps ensure that the most cost effective practices are implemented first.
5. Allows for the evaluation of the adequacy of the TMDL in achieving water quality standards.

6.3 Implementation of Wasteload Allocations

Federal regulations require that all new or revised National Pollutant Discharge Elimination System (NPDES) permits must be consistent with the assumptions and requirements of any applicable TMDL WLA (40 CFR §122.44 (d)(1)(vii)(B)). All such permits should be submitted to EPA for review.

For the implementation of the WLA component of the TMDL, the Commonwealth utilizes the Virginia NPDES program (VPDES) and the Virginia Stormwater Management Program (VSMP). Requirements of the permit process should not be duplicated in the TMDL process; depending on the type and nature of a point source discharge, it may be addressed through the development of TMDL implementation plans, or it may be addressed solely through the discharge permit. However, it is recognized that implementation plan development may help to coordinate the efforts of permitted sources through the collaborative process involved in development of the plan.

6.3.1 Treatment Plants

This TMDL does not require reductions from municipal or industrial treatment plants. These facilities are required to meet the bacteria criterion of the Virginia WQS at the point of discharge as stipulated in the VPDES permit.

6.3.2 Stormwater

VADEQ and DCR coordinate separate state permitting programs that regulate the management of pollutants carried by stormwater runoff. VADEQ regulates stormwater discharges associated with industrial activities through its VPDES program, while DCR regulates stormwater discharges from construction sites, and from municipal separate storm sewer systems (MS4s) through the Virginia Stormwater Management Program (VSMP). As with non-stormwater permits, all new or revised stormwater permits must be consistent with the assumptions and requirements of any applicable TMDL WLA. If a WLA is based on conditions specified in existing permits, and the permit conditions are being met, no additional actions may be needed. If a WLA is based on reduced pollutant loads, additional pollutant control actions will need to be implemented.

Municipal Separate Storm Sewer Systems – MS4s

For MS4/VSMP general permits, the Commonwealth expects the permittee to specifically address the TMDL wasteload allocations (WLA) for stormwater through the iterative implementation of programmatic BMPs. BMP effectiveness is determined through permittee implementation of an individual control strategy that includes a monitoring program that is sufficient to determine its effectiveness. As stated in EPA's Memorandum on TMDLs and Stormwater Permits, dated November 22, 2002, "The NPDES permits must require the monitoring necessary to assure compliance under the permit limits." Ambient instream monitoring would not be an appropriate means of determining permit compliance. Ambient monitoring would be appropriate to determine if the entire TMDL is being met by all attributed sources. This is in accordance with recent EPA guidance. If future monitoring indicates no improvement in the quality of the regulated discharge, the permit could require the MS4 to expand or better tailor its stormwater management program to achieve the TMDL wasteload allocation. However, only failing to implement the programmatic BMPs identified in the modified stormwater management program would be considered a permit compliance issue. Any alterations to the TMDL resulting from changes to water quality standards for Holmes Run, Cameron Run, and Hunting Creek would be reflected in the permit.

Wasteload allocations for stormwater discharges from storm sewer systems covered by a MS4 permit will be addressed as a condition of the MS4 permit. An implementation plan will identify types of corrective actions and strategies to obtain the load allocation for the pollutant causing the water quality impairment. Permittees will be required encouraged to participate in the development of TMDL implementation plans since recommendations from the process may result in modifications to the stormwater management plan in order to meet the TMDL. For example, MS4 permittees regulate erosion and sediment control programs that affect discharges that are not regulated by the MS4 permit. The implementation of the WLAs for MS4 permits will focus on achieving the percent reductions required by the TMDL, rather than the individual numeric WLAs.

Additional information on Virginia's Stormwater Phase 2 program and a downloadable menu of Best Management Practices and Measurable Goals Guidance can be found at http://www.dcr.virginia.gov/sw/vsmp.htm. .

6.3.3 TMDL Modifications for New or Expanding Dischargers

Permits issued for facilities with WLAs developed as part of a TMDL must be consistent with the assumptions and requirements of these WLAs, per EPA regulations. In cases where a proposed permit modification is affected by a TMDL WLA, permit and TMDL staff must coordinate to ensure that new or expanding discharges meet this requirement. In 2005, VADEQ issued guidance memorandum 05-2011 describing the available options and the process that should be followed under those circumstances, including public participation, EPA approval, State Water Control Board actions, and coordination between permit and TMDL staff. The guidance memorandum is available on VADEQ's web site at http://www.deq.virginia.gov/waterguidance. .

6.3.4 Combined Sewer Overflow (CSO) Long Term Control Programs (LTCP)

Implementation of the TMDL for the City of Alexandria's Combined Sewer System will be accomplished through the VPDES permit. The permit for the COA CSS, VPDES permit number VA0087068, expires January 2012. The reissuance of the permit will reflect the provisions of the TMDL, and will be done in accordance with EPA's CSO Control Policy. Consistent with the CSO Control Policy, the Long Term CSO Control Plan (LTCP) is the mechanism for developing and implementing plans that will achieve compliance with Water Quality Standards (WQS). The current, approved LTCP of the City will need to be updated to address the TMDL. Revision of the LTCP may result in a number of possible outcomes, consistent with the flexibility incorporated into the CSO Control Policy. A water quality standards review, whereby WQS may be adapted to reflect site-specific conditions, is one such option discussed in the CSO Control Policy (see discussion under Section 6.8, Attainability of Designated Uses). Should that occur, to include State Water Control Board and EPA approval, this TMDL will be updated to reflect those site-specific conditions as well. This TMDL reflects one allocation scenario. If the TMDL is updated to reflect site-specific criteria, the department may consider alternative scenarios based on additional monitoring or other information. It should be noted that in addition to the current LTCP, the City has implemented a Combined Sewer Service Area Reduction Plan (2005) with the goal of separating the combined sewer system. Update of the LTCP may consider the current enforceable and non-enforceable control programs of the City.

6.4 Implementation of Load Allocations

The TMDL program does not impart new implementation authorities. Therefore, the Commonwealth intends to use existing programs to the fullest extent in order to attain its water quality goals. The measures for nonpoint source reductions, which can include the use of better treatment technology and the installation of BMPs, are implemented in an iterative process that is described along with specific BMPs in the TMDL implementation plan.

6.4.1 Implementation Plan Development

A TMDL implementation plan will be developed that addresses, at a minimum, the requirements specified in the Code of Virginia, Section 62.1-44.19.7. State law directs the State Water Control Board to "develop and implement a plan to achieve fully supporting status for impaired waters." The implementation plan "shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated costs, benefits and environmental impacts of addressing the impairments." EPA outlines the minimum elements of an approvable implementation plan in its 1999 "Guidance for Water Quality-Based Decisions: The TMDL Process." The listed elements include implementation actions/management measures, timelines, legal or regulatory controls, time required to attain water quality standards, monitoring plans, and milestones for attaining water quality standards.

In order to qualify for other funding sources, such as EPA's Section 319 grants, additional plan requirements may need to be met. The detailed process for developing an implementation plan has been described in the "TMDL Implementation Plan Guidance Manual," published in July 2003 and available upon request from the VADEQ and DCR TMDL project staff or at http://www.deq.virginia.gov/tmdl/implans/ipguide.pdf. .

Watershed stakeholders will have opportunities to provide input and to participate in the development of the TMDL implementation plan. Regional and local offices of VADEQ, DCR, and other cooperating agencies are technical resources that can assist in this endeavor.

With successful completion of implementation plans, local stakeholders will have a blueprint to restore impaired waters and enhance the value of their land and water resources. Additionally, development of an approved implementation plan may enhance opportunities for obtaining financial and technical assistance during implementation.

6.4.2 Staged Implementation Scenarios

The purpose of the staged implementation scenarios is to identify one or more combinations of implementation actions that will result in the reduction of controllable sources to the maximum extent practicable using cost-effective, reasonable BMPs for nonpoint source control. Some examples of effective bacterial BMPs for both urban and rural watersheds are the stream side fencing for cattle farms (rural areas), pet waste clean-up programs (urban and rural areas) and government grant programs available to homeowners with failing septic systems and installation of treatment systems for homeowners currently using straight pipes (predominantly rural areas). Among the most efficient sediment BMPs for both urban and rural watersheds are infiltration and retention basins, riparian buffer zones, grassed waterways, streambank protection and stabilization, and wetland development or enhancement.

VADEQ expects that implementation of the bacteria TMDLs will occur in stages, and that full implementation of the TMDLs is a long-term goal. Implementation efforts will focus on controlling anthropogenic sources. Specific goals for phased implementation will be determined after the COA's LTCP for CSOs is revised (See Section 6.34.).

Actions identified during TMDL implementation plan development that go beyond what can be considered cost-effective and reasonable will only be included as implementation actions if there are reasonable grounds for assuming that these actions will in fact be implemented.

If water quality standards are not met upon implementation of all cost-effective and reasonable BMPs, a Use Attainability Analysis (UAA) may need to be initiated since Virginia's water quality standards allow for changes to use designations if existing water quality standards cannot be attained by implementing effluent limits required under §301b and §306 of Clean Water Act, and cost-effective and reasonable BMPs for nonpoint source control. Additional information on UAAs is presented in Section 6.6, Attainability of Designated Uses.

6.4.3 Link to Ongoing Restoration Efforts

Implementation of this TMDL will contribute to on-going water quality improvement efforts aimed at restoring water quality in the Cameron Run/Hunting Creek watershed, the Potomac River, and the Chesapeake Bay. Links to on-going restoration efforts are described in more detail below.

Chesapeake Bay Program Ordinances

Fairfax County, Arlington County, the City of Falls Church, and the City of Alexandria all have adopted Chesapeake Bay Program Ordinances which require stormwater BMPs for all new development or redevelopment.

Other Jurisdictional Programs

Fairfax County, Arlington County, the City of Falls Church, and the City of Alexandria all have pet waste ordinances requiring proper disposal of pet wastes. All of the jurisdictions have programs for indentifying illicit discharges to storm sewer systems, cleaning storm sewer catchments and basins, and rehabilitating sanitary sewers to prevent sanitary sewer overflow. Arlington County, the City of Falls Church, and the City of Alexandria have street sweeping programs; VDOT, which maintains the roads in Fairfax County, also has a street sweeping program in that jurisdiction.

Each jurisdiction is working to affect the behaviors and attitudes of the basin's citizens to non-point source pollution. For instance, outreach campaigns have been launched to address illegal dumping in storm drains. While some of these programs address broad water quality issues, some jurisdictions are also conducting directed outreach efforts relating to bacteria reduction. For example, the jurisdictions have made efforts to emphasize on proper dog walking habits and the watersheds' relationship to the Chesapeake Bay.

Cameron Run Stream Restoration Feasibility Study

Fairfax County and the City of Alexandria are working with the U.S. Army Corps of Engineers and the Northern Virginia Regional Commission to develop a stream restoration plan for Cameron Run (USACE, 2007). The plan focuses on controlling the impacts of stormwater, and has multiple objectives: stream restoration, riparian habitat restoration, and cost-effective flood control. Control of stormwater may reduce the delivery of bacteria from impervious surfaces to streams in the Cameron Run watershed. Stream corridor restoration potentially may lower bacteria concentrations by restoring an ecological balance to riparian areas.

Cameron Run and Belle Haven Watershed Plans

The Fairfax County Board of Supervisors approved a Watershed Plan for Cameron Run on August 6, 2007. The objectives of the plan are aligned with the joint stream restoration plan for Cameron Run describe above. The plan identifies a list of structural projects and non-structural actions that could be implemented in the next 25 years (Versar, 2007). The plan will help identify strategies to control stormwater runoff and its associated pollutant loads, which will help meet the load reductions set forth in this TMDL.

A similar plan for the Belle Haven watershed is in development.

City of Alexandria's CSO Long Term Control Plan

The City of Alexandria developed and implemented a Long-Term CSO Control Program (LTCP) in the early 1990s which is comprised of the Nine Minimum Controls (NMCs) discussed in the CSO Control Policy. The NMCs are summarized as:

1. Proper operation and regular maintenance programs for the sewer system and the CSOs;
2. Maximum use of the collection system for storage;
3. Review and modification of pretreatment requirements to assure CSO impacts are minimized;
4. Maximization of flow to the publicly owned treatment works for treatment;
5. Prohibition of CSOs during dry weather;
6. Control of solid and floatable materials in CSOs;
7. Pollution prevention;
8. Public notification to ensure that the public receives adequate notification of CSO occurrences and CSO impacts;
9. Monitoring to effectively characterize CSO impacts and the efficacy of CSO controls;

Additionally, the City has implemented a non-regulatory Combined Sewer Service Area Reduction Plan (2005) which comprises sewer separation projects. As noted in Section 6.3.4. the current approved LTCP of the City will need to be updated to address the TMDL.

6.4.4 Implementation Funding Sources

The implementation of pollutant reductions from non-regulated nonpoint sources relies heavily on incentive-based programs, while the funding sources for regulated discharges can be varied depending on the type of discharge. Therefore, the identification of funding sources for non-regulated implementation activities is a key to success. Cooperating agencies, organizations, and stakeholders must identify potential funding sources available for implementation during the development of the implementation plan in accordance with the "Virginia Guidance Manual for Total Maximum Daily Load Implementation Plans." The TMDL Implementation Plan Guidance Manual contains information on a variety of funding sources and government agencies that might support implementation efforts, as well as suggestions for integrating TMDL implementation with other watershed planning efforts.

Some of the major potential sources of funding for non-regulated implementation actions include EPA Section 319 funds, Virginia State Revolving Loan Program (also available for permitted activities), Virginia Agricultural Best Management Practices Cost-Share Programs, Virginia Water Quality Improvement Fund (available for both point and nonpoint source pollution), tax credits and landowner contributions. With additional appropriations for the Water Quality Improvement Fund during the last two legislative sessions, the Fund has become a significant funding stream for WWTPs. Additionally, funding is being made available to address urban and residential water quality problems. Information on WQIF projects and allocations can be found at http://www.deq.virginia.gov/bay/wqif.html and at http://www.dcr.virginia.gov/sw/wqia.htm. .

6.5 Follow-Up Monitoring

Following the development of the TMDL, VADEQ will make every effort to continue to monitor the impaired stream in accordance with its ambient monitoring program. VADEQ's Ambient Watershed Monitoring Plan for conventional pollutants calls for watershed monitoring to take place on a rotating basis, bi-monthly for two consecutive years of a six-year cycle. In accordance with DEQ Guidance Memo No. 03-2004, during periods of reduced resources, monitoring can temporarily discontinue until the TMDL staff determines that implementation measures to address the source(s) of impairments are being installed. Monitoring can resume at the start of the following fiscal year, next scheduled monitoring station rotation, or where deemed necessary by the regional office or TMDL staff, as a new special study. The purpose, location, parameters, frequency, and duration of the monitoring will be determined by VADEQ staff, in cooperation with DCR staff, the Implementation Plan Steering Committee, and local stakeholders. Whenever possible, the location of the follow-up monitoring station(s) will be the same as the listing station. At a minimum, the monitoring station must be representative of the original impaired segment. The details of the follow-up monitoring will be outlined in the Annual Water Monitoring Plan prepared by each VADEQ Regional Office. Other agency personnel, watershed stakeholders, etc. may provide input on the Annual Water Monitoring Plan. These recommendations must be made to the VADEQ regional TMDL coordinator by September 30 of each year. **Table 6-1** provides a summary of the water quality monitoring stations in the Holmes Run, Cameron Run, and Hunting Creek bacteria-impaired watersheds.

Table 6-1: Active VADEQ Water Quality Monitoring Stations in the Holmes Run, Cameron Run, and Hunting Creek Watersheds

Station ID	Station Description	Stream Name
1AHUT000.01	George Washington Memorial Pkwy	Hunting Creek (Tidal)
1AHUT001.72	Telegraph Road	Hunting Creek (Tidal)
1ACAM002.92	Eisenhower Avenue	Cameron Run (Non-Tidal)
1AHOR001.04	Pickett Street (off Holmes Run Pkwy @ Park)	Holmes Run (Non-Tidal)
1ABAL001.40	Rt. #401 Van Dorn Street	Backlick Run (Non-Tidal)

[1]Note: The last 5 digits of the VADEQ station number corresponds to stream mile.

VADEQ staff, in cooperation with DCR staff, the Implementation Plan Steering Committee and local stakeholders, will continue to use data from the ambient monitoring stations to evaluate reductions in pollutants ("water quality milestones" as established in the IP), the effectiveness of the TMDL in attaining and maintaining water quality standards, and the success of implementation efforts. Recommendations may then be made, when necessary, to target implementation efforts in specific areas and continue or discontinue monitoring at follow-up stations.

In some cases, watersheds will require monitoring above and beyond what is included in VADEQ's standard monitoring plan. Ancillary monitoring by local government, citizens' or watershed groups, local government, or universities is an option that may be used in such cases. An effort should be made to ensure that ancillary monitoring follows established QA/QC guidelines in order to maximize compatibility with VADEQ monitoring data. In instances where citizens' monitoring data is not available and additional monitoring is needed to assess the effectiveness of targeting efforts, TMDL staff may request of the monitoring managers in each regional office an increase in the number of stations or monitor existing stations at a higher frequency in the watershed. The additional monitoring beyond the original bimonthly single station monitoring will be contingent on staff resources and available laboratory budget. More information on citizen monitoring in Virginia and QA/QC guidelines is available at http://www.deq.virginia.gov/cmonitor/. .

To demonstrate that the watershed is meeting water quality standards in watersheds where corrective actions have taken place (whether or not a TMDL or Implementation plan has been completed), VADEQ must meet the minimum data requirements from the original listing station or a station representative of the originally listed segment. The minimum data requirement for conventional pollutants (bacteria, dissolved oxygen, etc) is bimonthly monitoring for two consecutive years. For biological monitoring, the minimum requirement is two consecutive samples (one in the spring and one in the fall) in a one year period.

6.6 Addressing Wildlife Contributions

In some streams for which TMDLs have been developed, water quality modeling indicates that even after removal of all bacteria sources (other than wildlife), the stream will not attain standards under all flow regimes at all times. Virginia and USEPA are not proposing the elimination of natural wildlife to allow for the attainment of water quality standards. However, managing overpopulations of wildlife remains an option available to local stakeholders. During the implementation plan development phase of a TMDL process, and in consultation with a local government or land owner(s), should the Department of Game and Inland Fisheries (VDGIF) determine that a population of resident geese, deer or other wildlife is a at "nuisance" levels, measures to reduce such populations may be deemed acceptable if undertaken under the supervision, or issued permit, of the VDGIF or the U.S. Fish and Wildlife Service as appropriate. Additional information on VDGIF's wildlife programs can be found at http://www.dgif.virginia.gov/hunting/va_game_wildlife/.

If water quality standards are not being met, a use attainability analysis (UAA) may be initiated to reflect the presence of naturally high bacteria levels due to uncontrollable sources. In some cases, the effort may never have to go to the UAA phase because the water quality standard exceedances attributed to wildlife in the model may have been very small and infrequent and within the margin of error.

6.7 Attainability of Designated Uses

In some streams for which TMDLs have been developed, factors may prevent the stream from attaining its designated use.

In order for a stream to be assigned a new designated use, or a subcategory of a use, the current designated use must be removed. To remove a designated use, the state must demonstrate that the use is not an existing use, and that downstream uses are protected. Such uses will be attained by implementing effluent limits required under §301b and §306 of Clean Water Act and by implementing cost-effective and reasonable best management practices for nonpoint source control (9 VAC 25-260-10 paragraph I).

The state must also demonstrate that attaining the designated use is not feasible because of one or more of the following reasons:

1. Naturally occurring pollutant concentration prevents the attainment of the use.
2. Natural, ephemeral, intermittent, or low flow conditions prevent the attainment of the use unless these conditions may be compensated for by the discharge of sufficient volume of effluent discharges without violating state water conservation.
3. Human-caused conditions or sources of pollution prevent the attainment of the use and cannot be remedied or would cause more environmental damage to correct than to leave in place.
4. Dams, diversions, or other types of hydrologic modifications preclude the attainment of the use, and it is not feasible to restore the waterbody to its original condition or to operate the modification in such a way that would result in the attainment of the use.
5. Physical conditions related to natural features of the waterbody, such as the lack of proper substrate, cover, flow, depth, pools, riffles, and the like, unrelated to water quality, preclude attainment of aquatic life use protection.
6. Controls more stringent than those required by §301b and §306 of the Clean Water Act would result in substantial and widespread economic and social impact.

This and other information is collected through a special study called a Use Attainability Analysis (UAA). All site-specific criteria or designated use changes must be adopted by the SWCB as amendments to the water quality standards regulations. During the regulatory process, watershed stakeholders and other interested citizens, as well as the EPA, are able to provide comment.

Additional information can be obtained at:
http://www.deq.virginia.gov/wqs/documents/WQS_eff_1FEB2010.pdf. .

The process to address potentially unattainable reductions based on the above is as follows:

As a first step, measures targeted at the controllable, anthropogenic sources identified discharge permits implementing provisions of the TMDL, or in the TMDLs' staged implementation plans will be implemented. The expectation would be for the reductions of all controllable sources to the maximum extent practicable using the implementation approaches described above. VADEQ will continue to monitor biological health and water quality in the stream during and subsequent to the implementation of these measures to determine if water quality standard is attained. This effort will also help to evaluate if the modeling assumptions were correct. In the best-case scenario, water quality goals will be met and the stream's uses fully restored using effluent controls and BMPs. If, however, water quality standards are not being met, and no additional effluent controls and BMPs can be identified, a UAA would then be initiated with the goal of re-designating the stream for a more appropriate use or subcategory of a use.

A 2006 amendment to the Code of Virginia under 62.1-44.19:7E. provides an opportunity for aggrieved parties in the TMDL process to present to the State Water Control Board reasonable grounds indicating that the attainment of the designated use for a water is not feasible. The Board may then allow the aggrieved party to conduct a use attainability analysis according to the criteria listed above and a schedule established by the Board. The amendment further states that "If applicable, the schedule shall also address whether TMDL development or implementation for the water shall be delayed."

7 Public Participation

Public participation figured prominently in the development of the Holmes Run, Cameron Run, and Hunting Creek Bacteria TMDLs. In addition to holding three technical advisory committee (TAC) meetings and three public meetings, which are standard components of the TMDL development process, VADEQ held three additional meetings with the City of Alexandria and other key stakeholders. Because of the potential impact the Hunting Creek Bacteria TMDL might have on the COA's CSS permit, these meetings focused in particular on the development of the TMDL for tidal waters. Discussion of topics raised at these meetings was also continued through formally-scheduled conference calls.

The following is a summary of the meetings and formal conference calls.

7.1 Technical Advisory Committee Meetings

<u>TAC Meeting No. 1</u> – The first TAC meeting was held on March10, 2009 at the Alexandria Beatley Central Library in Alexandria, Virginia. The purpose of the first TAC meeting was to present and review sources of data and the planned technical approach for the development of the bacteria TMDLs for Holmes Run, Cameron Run, and Hunting Creek. In addition, DEQ also requested additional data regarding the watershed from members of the TAC. 17 people attended this meeting.

<u>TAC Meeting No. 2</u> – The second TAC meeting was held on June 30, 2009 at the Alexandria Beatley Central Library in Alexandria, Virginia. The purpose of the second TAC meeting was to discuss preliminary results of the Cameron Run HSPF Model and to provide a detailed overview of the plans to use the ELCIRC model to develop the TMDL for tidal waters. In addition, DEQ also requested additional data regarding the watershed from members of the TAC. 16 people attended this meeting.

<u>TAC Meeting No. 3</u> – The third TAC meeting was held on June 25, 2010 at the Alexandria Beatley Central Library in Alexandria, Virginia. The TAC was given the opportunity to review the calibration of both the Cameron Run HSPF Model and the Hunting Creek ELCIRC Model. The determination of potential TMDL Scenarios for both tidal and nontidal waters was also discussed. The levels of

bacteria reductions required to meet water quality standards in Holmes Run and non-tidal Cameron Run were presented to TAC members. 14 people attended this meeting.

Between TAC Meeting No. 2 and No. 3 VADEQ circulated a memo dated October 19, 2009, with details of the source assessment for the Holmes Run, Cameron Run, and Hunting Creek TMDLs to all TAC members. The memo was essentially a summary of Section 3.5 of this report. TAC members were given the opportunity to comment on the source assessment and VADEQ formally responded to the comments received.

7.2 Public Meetings

Public Meeting No. 1 – The first public meeting was held on March 25, 2009 at the Dr. Oswald Durant Memorial Center in Alexandria, Virginia to present the TMDL development process, the location of the bacteria-impaired segments, data that caused the segments to be on the 303(d) list, and the data and information needed for TMDL development. Five people attended this meeting. Copies of the presentation were made available for public distribution. This meeting was publicly announced in the Virginia Register.

Public Meeting No. 2 – The second public meeting was held on June 30, 2010 at the Alexandria Beatley Central Library in Alexandria, Virginia. The presentation for the meeting focused on TMDL development for Holmes Run and Cameron Run. Twelve people attended this meeting. Copies of the presentation were available for public distribution. The meeting was announced publicly in the Virginia Register of Regulations.

Public Meeting No. 3 – The third public meeting was will be held on July 29, 2010 at the Alexandria Beatley Central Library in Alexandria, Virginia. The presentation for the meeting will focus on TMDL development for tidal Hunting Creek, but will include a presentation of TMDL allocations for Holmes Run and Cameron Run. [*number of people*] people attended this meeting. Copies of the presentation and the executive summary from the draft final report will be available for public distribution. The meeting was announced publicly in The Virginia Register of Regulations.

7.3 Additional Meetings and Communications with Stakeholders

VADEQ also initiated three other formal meetings with the COA and other key stakeholders. Generally these meetings discussed detailed technical and regulatory issues involved in the development of the TMDL for tidal Hunting Creek, and provided a greater opportunity for discussion. All of these meetings took place in advance of a scheduled TAC meeting and are therefore referred to as 'pre-TAC meetings."

<u>Pre-TAC Meeting No. 1</u> – The first pre-TAC meeting was held on March 6, 2009 at the Alexandria City Hall in Alexandria, Virginia. The purpose of this meeting was to present the planned technical approach for the development of the bacteria TMDL for Hunting Creek and the potential regulatory issues raised for Alexandria's CSS/CSO permit. Attendees included VADEQ staff and their technical consultants as well as the COA staff and their consultants.

<u>Pre-TAC Meeting No. 2</u> – The second pre-TAC meeting was held on February 9, 2010 at VADEQ's Northern Regional Office in Woodbridge, Virginia. The purpose of this meeting was to present results from the ELCIRC model and update stakeholders on development of the tidal Hunting Creek Bacteria TMDL. COA staff and their consultants attended the meeting. Representatives from Fairfax County also attended via conference call due to inclement weather.

<u>Pre-TAC Meeting No. 3</u> – The third pre-TAC meeting was held on June 11, 2010 at VADEQ's Northern Regional Office in Woodbridge, Virginia. The purpose of this meeting was to review results of potential TMDL Scenarios for the Holmes Run, Cameron Run, and Hunting Creek Bacteria TMDLs, and discuss their regulatory implications. Representatives from COA, Fairfax County, and Alexandria Sanitation Authority (ASA) attended, as well as consultants assisting COA, ASA, and VADEQ.

Pre-TAC Meetings 2 and 3 resulted in two sets of formal conference calls. COA requested weekly conference calls to expedite requests for information on TMDL development and further discuss technical and regulatory issues concerning the TMDLs. These weekly conference calls were initiated on June 21, 2010 and continued until [TBD].

Weekly Conference Call No. 1 - This call took place on June 21, 2010. The primary topics were the organization of communication during the final stages of TMDL development and COA's requests for information on the data and models used for TMDL development. During this conference call it was agreed to separate the discussion of technical issues related to the model from regulatory issues. Prospects for collaboration on the documentation of the TMDL were also discussed.

Weekly Conference Call No. 2 - This call took place on June 29, 2010. The primary topic of this conference call was to identify areas of agreement and disagreement on regulatory issues relating to the TMDL and to initiate collaboration in determining consensus on the documentation of the reasonable assurance of implementation and the relation between the TMDL implementation and the CSS permit.

As mentioned above, a second set of conference calls was organized to discuss technical issues related to the models, and to separate the discussion of the technical aspects of TMDL development from regulatory issues. The following three conference calls on modeling issues took place:

Modeling Conference Call No. 1 - This call took place on February 16, 2010, subsequent to pre-TAC Meeting 2. The primary topic was a comparison of the modeling work for the TMDL with the previous modeling work performed by COA's consultants for the LTCP. The discussion was led by consultants for COA and VADEQ with the participation of COA and VADEQ staff.

Modeling Conference Call No. 2 - Subsequent to pre-TAC Meeting 3, Dr. Harry Wang of the Virginia Institute of Marine Science (VIMS), who developed the ELCIRC model for Hunting Creek, gave a formal presentation of the calibration and technical development of the ELCIRC model of Hunting Creek for a representative of Limno-Tech, Inc. (LTI), a consultant for the City of Alexandria. The goal of the presentation was to initiate a more technical review of the ELCIRC model. VADEQ and ICPRB staff also participated in the conference call.

Modeling Conference Call No. 3 – The main topic of this conference call on July 7, 2010, was to provide COA and their consultants with the opportunity to specify request potential sensitivity runs of the ELCIRC model to better understand model performance, and to acquire additional technical information about the ELCIRC model. VIMS, ICPRB, VA DEQ, COA, and LTI all participated on the conference call.

Modeling Workshop – As a result of Modeling Conference Call No. 3, VIMS and ICPRB offered to meet in person with staff from LTI and the COA to demonstrate how the ELCIRC model works. The ELCIRC modeling "workshop" will be held during the public comment period for the report, on July 28, 2010 at VADEQ's Northern Regional Office in Woodbridge, Virginia.

7.4 List of Agencies and Organizations Contributing to TMDL Development

The following groups and agencies participated in the development of the bacteria TMDLs for Holmes Run, Cameron Run, and Hunting Creek:

- Fairfax County Stormwater Planning Division, DPWES
- City of Falls Church, Environmental Services
- Alexandria Sewer Sanitation Authority
- City of Alexandria Department of Transportation and Environmental Services
- City of Falls Church, Environmental Services
- Fairfax County Health Department
- Fairfax County Stormwater Planning Division, Department of Public Works and Environmental Services
- Fairfax Master Naturalists
- Greeley and Hanson
- The Interstate Commission on the Potomac River Basin
- Lake Barcroft Association
- LimnoTech, Inc.
- National Park Service, George Washington Memorial Parkway
- Northern Virginia Regional Commission
- Northern Virginia Soil Water Conservation District
- City of Alexandria Department of Transportation and Environmental Services
- Virginia Department of Conservation and Recreation
- Virginia Department of Forestry
- Virginia Institute of Marine Science
- Virginia Department of Environmental Quality
- Virginia Department of Forestry
- Virginia Institute of Marine Science
- Virginia Department of Transportation

Appendix A: Additional Tables for the Cameron Run HSPF Model

Table A-1: Pervious Land By Segment and Land Use

Subshed	Commercial	High Density Residential	Industrial	Low Density Residential	Medium Density Residential	Open Space	Transportation
10	156.84	56.81	7.69	567.86	1,134.87	212.61	183.05
20	539.57	155.03	17.66	474.41	1,342.40	633.95	433.92
30	27.70	55.01	0.00	251.11	453.92	60.12	82.50
40	285.49	137.41	3.26	244.41	842.04	324.12	74.50
50	62.94	112.61	14.67	423.65	232.39	408.38	110.47
60	129.23	37.11	5.73	459.10	275.01	170.25	123.60
70	424.48	206.99	399.46	575.23	1,212.84	669.64	466.33
80	118.85	91.19	23.33	172.96	705.22	221.48	94.02
90	42.35	220.78	0.00	0.24	518.88	30.81	34.38
100	128.40	61.72	22.15	194.75	370.85	285.24	168.33
110	28.16	32.13	19.45	288.73	232.14	63.65	38.95
120	36.51	51.23	2.20	27.78	147.01	72.87	35.37
130	83.87	54.89	0.00	0.00	12.29	6.43	64.16
140	4.44	55.87	22.89	4.00	16.78	43.10	63.14
150	1.26	26.50	0.00	0.00	0.00	3.70	27.59
160	0.00	0.00	0.00	0.00	0.00	20.96	0.26
170	0.85	4.24	0.51	4.56	20.61	115.52	17.35
180	0.00	0.00	0.00	0.00	0.00	9.66	15.33
190	0.00	3.71	0.00	0.00	0.00	21.87	3.07

Table A-2: Impervious Land By Segment and Land Use							
Subshed	**Commercial**	**High Density Residential**	**Industrial**	**Low Density Residential**	**Medium Density Residential**	**Open Space**	**Transportation**
10	189.70	38.35	17.45	76.32	209.49	13.34	429.98
20	217.71	99.30	15.11	51.28	209.90	29.30	535.05
30	18.67	25.07	0.00	18.96	60.65	2.60	127.49
40	292.74	160.04	1.47	47.67	295.83	15.56	136.51
50	60.82	57.03	17.04	49.57	34.20	14.73	138.89
60	119.93	23.17	5.44	47.13	38.91	10.35	158.59
70	510.29	179.90	287.70	66.78	206.01	59.21	659.96
80	54.10	37.59	3.68	10.13	106.56	9.74	181.99
90	100.83	135.56	0.00	0.45	205.82	8.56	12.18
100	92.67	44.56	60.99	29.96	97.09	19.99	106.14
110	77.37	32.39	9.13	75.88	99.65	8.81	37.36
120	79.11	47.10	1.01	1.46	24.47	7.22	73.76
130	153.14	18.96	0.00	0.00	2.84	2.70	53.42
140	15.06	28.65	23.14	1.15	2.79	6.81	42.82
150	1.53	14.69	0.00	0.00	0.00	1.33	42.24
160	0.00	0.00	0.00	0.00	0.00	0.00	0.00
170	1.61	3.11	0.03	0.51	4.45	3.72	11.53
180	0.00	0.00	0.00	0.00	0.00	0.13	4.51
190	0.00	10.26	0.00	0.00	0.00	6.84	2.83

Table A-3: Pervious Bacteria Accumulation Rate (cfu/d) By Segment and Land Use							
Subshed	Commercial	High Density Residential	Industrial	Low Density Residential	Medium Density Residential	Open Space	Transportation
10	3.84E+09	3.84E+09	3.84E+09	3.84E+09	3.84E+09	3.84E+09	3.84E+09
20	3.19E+09	3.19E+09	3.19E+09	3.19E+09	3.19E+09	3.19E+09	3.19E+09
30	2.94E+09	2.94E+09	0.00E+00	2.95E+09	2.94E+09	2.94E+09	2.94E+09
40	9.13E+09	9.13E+09	9.05E+09	9.13E+09	9.13E+09	9.13E+09	9.13E+09
50	3.47E+09	3.47E+09	3.48E+09	3.47E+09	3.47E+09	3.47E+09	3.47E+09
60	2.95E+09	2.95E+09	2.87E+09	2.95E+09	2.95E+09	2.95E+09	2.95E+09
70	4.75E+09	4.75E+09	4.75E+09	4.75E+09	4.75E+09	4.75E+09	4.75E+09
80	3.64E+09	3.64E+09	3.64E+09	3.64E+09	3.64E+09	3.64E+09	3.64E+09
90	9.36E+09	9.36E+09	9.28E+09	9.28E+09	9.36E+09	9.36E+09	9.36E+09
100	3.35E+09	3.35E+09	3.35E+09	3.35E+09	3.35E+09	3.35E+09	3.35E+09
110	4.55E+09	4.55E+09	4.55E+09	4.47E+09	4.55E+09	4.55E+09	4.55E+09
120	4.95E+09	4.95E+09	4.95E+09	4.95E+09	4.95E+09	4.95E+09	4.95E+09
130	5.20E+09	5.19E+09	0.00E+00	0.00E+00	5.12E+09	5.20E+09	5.19E+09
140	9.09E+09	9.09E+09	9.01E+09	9.01E+09	9.01E+09	9.09E+09	9.09E+09
150	8.35E+09	8.43E+09	0.00E+00	0.00E+00	0.00E+00	8.43E+09	8.43E+09
160	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.63E+07	0.00E+00
170	1.41E+09	1.49E+09	1.41E+09	1.41E+09	1.49E+09	1.49E+09	1.49E+09
180	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.98E+07	9.12E+07
190	0.00E+00	7.19E+08	0.00E+00	0.00E+00	0.00E+00	7.21E+08	7.14E+08

Table A-4: Impervious Bacteria Accumulation Rate (cfu/d) By Segment and Land Use

Subshed	Commercial	High Density Residential	Industrial	Low Density Residential	Medium Density Residential	Open Space	Transportation
10	8.22E+08	8.22E+08	8.22E+08	8.22E+08	8.22E+08	8.23E+08	8.22E+08
20	8.90E+08	8.90E+08	8.89E+08	8.90E+08	8.90E+08	8.95E+08	8.89E+08
30	1.11E+09	1.11E+09	0.00E+00	1.12E+09	1.11E+09	1.11E+09	1.11E+09
40	1.68E+09	1.68E+09	1.68E+09	1.68E+09	1.68E+09	1.69E+09	1.68E+09
50	1.14E+09	1.14E+09	1.14E+09	1.14E+09	1.14E+09	1.14E+09	1.14E+09
60	7.80E+08	7.80E+08	7.80E+08	7.81E+08	7.80E+08	7.85E+08	7.80E+08
70	8.64E+08	8.63E+08	8.64E+08	8.64E+08	8.64E+08	8.66E+08	8.64E+08
80	1.16E+09	1.16E+09	1.16E+09	1.16E+09	1.16E+09	1.17E+09	1.16E+09
90	1.57E+09	1.57E+09	1.57E+09	1.57E+09	1.57E+09	1.57E+09	1.57E+09
100	8.21E+08	8.20E+08	8.20E+08	8.21E+08	8.21E+08	8.23E+08	8.21E+08
110	8.52E+08	8.52E+08	8.52E+08	8.52E+08	8.52E+08	8.54E+08	8.52E+08
120	7.19E+08	7.19E+08	7.19E+08	7.22E+08	7.20E+08	7.23E+08	7.19E+08
130	4.53E+08	4.53E+08	0.00E+00	0.00E+00	4.53E+08	4.54E+08	4.53E+08
140	1.51E+09	1.51E+09	1.51E+09	1.51E+09	1.51E+09	1.51E+09	1.51E+09
150	7.61E+08	7.61E+08	0.00E+00	0.00E+00	0.00E+00	7.61E+08	7.61E+08
160	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.98E+10	0.00E+00
170	8.76E+08	8.77E+08	8.76E+08	8.76E+08	8.77E+08	8.85E+08	8.77E+08
180	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.37E+07	3.22E+06
190	0.00E+00	1.42E+08	0.00E+00	0.00E+00	0.00E+00	1.43E+08	1.42E+08

Table A-5: Average Annual EOS *E. coli* Load (cfu/yr) by Segment and Land Use

Subshed	Direct Deposit	Open Space	Transportation	Commercial	Industrial	Low Density Residential	Medium Density Residential	High Density Residential	TOTAL
10	1.38E+12	4.51E+12	3.55E+13	1.70E+13	1.45E+12	1.51E+13	3.45E+13	3.84E+12	1.13E+14
20	2.77E+12	1.11E+13	4.99E+13	2.53E+13	1.48E+12	1.07E+13	3.56E+13	1.03E+13	1.47E+14
30	9.21E+11	1.04E+12	1.43E+13	2.29E+12	0.00E+00	5.19E+12	1.21E+13	3.29E+12	3.92E+13
40	1.93E+12	1.57E+13	2.50E+13	5.88E+13	3.68E+11	1.76E+13	8.18E+13	3.14E+13	2.33E+14
50	1.62E+12	6.79E+12	9.11E+12	4.20E+12	1.13E+12	8.88E+12	5.24E+12	4.72E+12	4.17E+13
60	1.26E+12	2.58E+12	7.60E+12	6.20E+12	2.78E+11	7.65E+12	4.99E+12	1.35E+12	3.19E+13
70	3.99E+12	1.61E+13	3.72E+13	3.00E+13	2.02E+13	1.45E+13	3.33E+13	1.18E+13	1.67E+14
80	1.54E+12	4.08E+12	1.40E+13	5.56E+12	6.11E+11	3.35E+12	1.82E+13	4.00E+12	5.13E+13
90	7.00E+11	4.86E+12	5.92E+12	2.36E+13	0.00E+00	1.11E+11	9.36E+13	4.87E+13	1.77E+14
100	1.37E+12	5.30E+12	8.00E+12	6.71E+12	3.48E+12	4.46E+12	1.06E+13	3.22E+12	4.31E+13
110	6.68E+11	4.41E+12	6.16E+12	9.90E+12	2.04E+12	2.36E+13	2.34E+13	5.25E+12	7.54E+13
120	5.63E+11	1.87E+12	3.98E+12	4.23E+12	9.10E+10	6.55E+11	4.20E+12	3.15E+12	1.87E+13
130	3.22E+11	5.76E+11	7.31E+12	1.45E+13	0.00E+00	0.00E+00	9.49E+11	4.66E+12	2.84E+13
140	1.10E+11	2.18E+12	6.04E+12	1.47E+12	2.84E+12	2.46E+11	8.56E+11	4.54E+12	1.83E+13
150	6.99E+10	4.97E+11	6.81E+12	2.72E+11	0.00E+00	0.00E+00	0.00E+00	4.06E+12	1.17E+13
160	9.45E+09	9.94E+09	5.58E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.94E+10
170	2.63E+11	9.64E+11	7.44E+11	9.29E+10	4.74E+09	5.64E+10	3.79E+11	1.97E+11	2.70E+12
180	1.26E+11	6.34E+09	9.89E+09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.42E+11
190	7.65E+10	3.82E+11	9.18E+10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.52E+11	8.03E+11
Holmes Run	6.99E+12	3.23E+13	1.25E+14	1.03E+14	3.30E+12	4.86E+13	1.64E+14	4.88E+13	5.32E+14
Cameron Run	1.68E+13	6.72E+13	2.01E+14	1.56E+14	2.90E+13	8.74E+13	2.36E+14	7.38E+13	8.67E+14
Hunting Creek	1.97E+13	8.29E+13	2.38E+14	2.10E+14	3.40E+13	1.12E+14	3.60E+14	1.45E+14	1.20E+15

Appendix B: Cameron Run HSPF Model Sensitivity Analysis

The sensitivity analysis of the bacteria loadings and the waterbody response provides a better understanding of the watershed conditions that lead to the water quality criteria exceedance and provides insight and direction in developing the TMDL allocation and implementation. Potential sources of fecal coliform include non-point (land-based) sources such as failed septic systems, sanitary sewer overflows, pet and wildlife. Some of these sources are dry weather driven and others are wet weather driven.

The objective of the sensitivity analysis was to assess the impacts of variation of model calibration parameters on the simulation of flow and the exceedance of the bacteria criteria in nontidal Cameron Run. For the 2001-2005 calibration period, the model was run with 110 percent and 90 percent of calibrated values of key hydrological parameters. The scenarios that were analyzed include the following:

- 10% increase/decrease in LZSN (the lower zone nominal storage)
- 10% increase/decrease in INFILT (index to the infiltration capacity of the soil)
- 10% increase/decrease in AGWRC (the basic groundwater recession rate)
- 10% increase/decrease in UZSN (the upper zone nominal storage)
- 10% increase/decrease in INTFW (the interflow/surface runoff partition parameter)
- 10% increase/decrease in IRC (the interflow recession parameter)
- 10% increase/decrease in LZETP (the lower zone evapotranspiration parameter)

The modeled flows for different sensitivity runs were compared with observed flows at the gage and the coefficients of determination of the hydrologic sensitivity analysis are presented in **Table B-1**. Based on this table it can be seen that the coefficient of determination is not very sensitive to changes in these hydrological parameters

The sensitivity analysis was also performed for two water quality parameters, WSQOP and FSTDEC, by simulating *E. coli* concentrations for 120 % and 80 % of their calibrated values. The rates of exceedance of the calendar-month geometric mean water quality criterion in Cameron Run and Holmes Run were determined for each sensitivity scenario and compared with the rates of exceedance under the water quality calibration run. The changes in the rate of exceedance are presented in **Table B-2**. The results of the sensitivity analysis show that the rate at which the geometric mean criterion is exceeded is fairly sensitive to the values of the parameters WSQOP and FSTDEC.

Table B-1: Sensitivity Analysis: Variation in Coefficient of Determination With Respect to Variation in Parameters For Simulation Period 2001-2005

Parameter	Coefficient of Determination	
	+10% change in parameter	-10% change in parameter
LZSN	0.760	0.766
INFILT	0.760	0.764
AGWRC	0.760	0.768
UZSN	0.763	0.764
INTFW	0.761	0.764
IRC	0.762	0.763
LZETP	0.762	0.762
Calibrated Parameters		0.763

Table B-2: Sensitivity Analysis: Change in *E. coli* Exceedance Rate From 20% Change in Calibration Parameter Values

Segment	Calibrated Parameters	WSQOP		FSTDEC	
		20%	-20%	20%	-20%
Cameron Run	71%	71%	67%	58%	71%
Holmes Run	54%	63%	63%	46%	64%

Appendix C: Summary of TMDL Scenario Runs for Hunting Creek

Section 5.2.2 of the report provides information on the assumptions that were used in the TMDL scenario runs of the ELCIRC model for Hunting Creek. Two sets of TMDL scenarios runs were performed. The first set of TMDL Scenario Runs (Scenarios 1-T through 5-T) assumed that the boundary between Hunting Creek at the Potomac River was set at the water quality standards. This was accomplished by using the following principles:

- The concentration at the model domain boundary on the Potomac River at DCDOE monitoring stations PMS37 and PMS55 were set at a constant value of 195 cfu/ 100 ml (fecal coliform bacteria). Potomac River flows were represented as actual flows during the model simulation period 2004 and 2005.

- The concentrations of all input sources in the extended Potomac domain were set at a constant concentration of 195 cfu/ 100 ml. These include (1) Blue Plains outfalls 001 and 002; (2) COA CSO outfall 001; (3) direct drainage from portions of Virginia outside of the Hunting Creek impairment (Segments 210 and 220); direct drainage from DC (Segment 230) and Maryland (250); and Oxon Run (Segment 240). Flows from all sources were represented as actual flows during the model period for point source discharges (e.g. Blue Plains, CSO outfall 001) and modeled HSPF flows for the remaining model segments.

- The decay rate in the Potomac River was set at 0.0 /day

The second set of TMDL scenario runs (Scenarios 6-T through 10-T) generally made the same assumptions as the first set of TMDL scenarios runs, except that a decay rate of 0.1/day was applied to sources entering the Potomac River.

Both boundary condition approaches ensure that sources outside of the Hunting Creek impairment in Maryland, the District of Columbia, and Virginia are not required to make reductions in excess of those required to meet water quality standards in their respective jurisdictions at the point of discharge.

The assumptions used for each TMDL Scenario are listed in Table C-1. Tables C-2 through C-11 show the results (geometric mean for each month during 2004 and 2005 for the two assessment areas of Hunting Creek - “Upstream Hunting Creek” and “Hunting Creek Embayment”) of each TMDL Scenario. It should be noted that for Scenarios 6-T, 7-T, and 8-T the model was only run for 2004.

For all TMDL scenarios, ASA’s WWTP was set at a design flow of 66 MGD, discharging at 195 cfu/100mL of fecal coliform bacteria (equivalent to the geometric mean water quality criterion for *E. coli*, 126 cfu/100mL). The only source loading input that was altered for each scenario was the loading from the COA’s CSS.

The final TMDL scenario selected for Hunting Creek is Scenario 10-T.

Table C-1: Potential Tidal Hunting Creek TMDL Scenario Definitions

Scenario	Reductions in Upstream Loads (Segment 100) and Direct Drainage (Segments 120, 140, 160-180)			Reductions in Hoofs Run Loads (Segment 90) and Direct Drainage (Segments 110, 130, 150, and 190)			CSO Reductions		ASA WWTP	Boundary Condition
	Human	Direct Deposition Wildlife	EOS	Human	Direct Deposition Wildlife	EOS	Outfall 002	Outfalls 003 and 004		
1-T	100%	50%	83%	100%	50%	98%	0%	0%	195 cfu/100mL 66MGD	Potomac Sources set at 195 cfu/100mL Decay Rate of Potomac River set at 0.0/day
2-T							95%	95%		
3-T							75%	99%		
4-T							50%	98%		
5-T							85%	99%		
6-T*	100%	50%	83%	100%	50%	98%	35%	99%	195 cfu/100mL 66MGD	Potomac Sources set at 195 cfu/100mL Decay Rate of Potomac River set at 0.1/day
7-T*							50%	99%		
8-T*							65%	99%		
9-T							75%	99%		
10-T							80%	99%		

**** Scenarios 6-T, 7-T, and 8-T were only run for 2004.***

Table C-2: Results of TMDL Scenario 1-T. Geometric means (*E. coli*), by month, for 2004 and 2005 at the "Upstream Hunting Creek" and "Hunting Creek Embayment" assessment areas. Geometric means that exceed the water quality criterion of 126 cfu/100mL are highlighted in red.

	2004		2005	
Month	**Upstream Hunting Creek**	**Hunting Creek Embayment**	**Upstream Hunting Creek**	**Hunting Creek Embayment**
January	57	98	160	133
February	119	129	116	110
March	118	115	185	156
April	95	128	99	131
May	180	137	158	178
June	212	176	137	143
July	345	222	323	189
August	204	172	131	133
September	155	140	59	99
October	149	120	143	174
November	183	154	95	118
December	118	130	209	135

Table C-3: Results of TMDL Scenario 2-T. Geometric means (*E. coli*), by month, for 2004 and 2005 at the "Upstream Hunting Creek" and "Hunting Creek Embayment" assessment areas. Geometric means that exceed the water quality criterion of 126 cfu/100mL are highlighted in red.

	2004		2005	
Month	**Upstream Hunting Creek**	**Hunting Creek Embayment**	**Upstream Hunting Creek**	**Hunting Creek Embayment**
January	57	98	95	104
February	108	114	104	102
March	93	99	104	108
April	74	101	66	107
May	109	102	66	106
June	76	105	70	101
July	109	109	100	107
August	106	112	79	103
September	87	106	57	99
October	92	102	85	116
November	95	104	77	101
December	75	100	127	103

Table C-4: Results of TMDL Scenario 3-T. Geometric means (*E. coli*), by month, for 2004 and 2005 at the "Upstream Hunting Creek" and "Hunting Creek Embayment" assessment areas. Geometric means that exceed the water quality criterion of 126 cfu/100mL are highlighted in red.

	2004		2005	
Month	**Upstream Hunting Creek**	**Hunting Creek Embayment**	**Upstream Hunting Creek**	**Hunting Creek Embayment**
January	54	97	88	108
February	108	117	101	103
March	89	102	101	120
April	72	108	63	112
May	104	109	59	122
June	72	121	63	111
July	99	135	93	123
August	101	124	76	109
September	81	115	50	97
October	84	105	78	126
November	89	115	74	104
December	70	106	123	110

Table C-5: Results of TMDL Scenario 4-T. Geometric means (*E. coli*), by month, for 2004 and 2005 at the "Upstream Hunting Creek" and "Hunting Creek Embayment" assessment areas. Geometric means that exceed the water quality criterion of 126 cfu/100mL are highlighted in red.

	2004		2005	
Month	**Upstream Hunting Creek**	**Hunting Creek Embayment**	**Upstream Hunting Creek**	**Hunting Creek Embayment**
January	54	97	92	114
February	109	121	102	105
March	91	106	108	132
April	74	115	65	118
May	109	118	66	138
June	84	138	68	121
July	116	162	107	142
August	108	138	81	117
September	89	124	51	98
October	89	109	82	138
November	96	127	75	109
December	73	113	128	118

Table C-6: Results of TMDL Scenario 5-T. Geometric means (*E. coli*), by month, for 2004 and 2005 at the "Upstream Hunting Creek" and "Hunting Creek Embayment" assessment areas. Geometric means that exceed the water quality criterion of 126 cfu/100mL are highlighted in red.

	2004		2005	
Month	**Upstream Hunting Creek**	**Hunting Creek Embayment**	**Upstream Hunting Creek**	**Hunting Creek Embayment**
January	54	97	86	105
February	108	116	101	102
March	89	100	99	114
April	71	104	63	109
May	102	105	56	114
June	68	113	61	105
July	93	122	88	114
August	99	118	74	106
September	78	111	50	97
October	82	103	77	120
November	86	109	73	102
December	69	103	121	106

Table C-7: Results of TMDL Scenario 6-T. Geometric means (*E. coli*), by month, for 2004 at the "Upstream Hunting Creek" and "Hunting Creek Embayment" assessment areas. Geometric means that exceed the water quality criterion of 126 cfu/100mL are highlighted in red.

	2004	
Month	**Upstream Hunting Creek**	**Hunting Creek Embayment**
January	57	93
February	107	117
March	93	103
April	76	115
May	110	117
June	85	140
July	114	167
August	108	138
September	91	125
October	91	108
November	96	127
December	75	112

Table C-8: Results of TMDL Scenario 7-T. Geometric means (*E. coli*), by month, for 2004 at the "Upstream Hunting Creek" and "Hunting Creek Embayment" assessment areas. Geometric means that exceed the water quality criterion of 126 cfu/100mL are highlighted in red.

	2004	
Month	**Upstream Hunting Creek**	**Hunting Creek Embayment**
January	57	93
February	107	115
March	92	101
April	76	111
May	109	112
June	81	132
July	109	154
August	106	132
September	88	121
October	90	106
November	94	122
December	74	109

Table C-9: Results of TMDL Scenario 8-T. Geometric means (*E. coli*), by month, for 2004 at the "Upstream Hunting Creek" and "Hunting Creek Embayment" assessment areas. Geometric means that exceed the water quality criterion of 126 cfu/100mL are highlighted in red.

	2004	
Month	**Upstream Hunting Creek**	**Hunting Creek Embayment**
January	57	93
February	107	113
March	92	99
April	75	107
May	107	108
June	76	123
July	103	140
August	104	125
September	86	116
October	88	104
November	92	116
December	73	105

Table C-10: Results of TMDL Scenario 9-T. Geometric means (*E. coli*), by month, for 2004 and 2005 at the "Upstream Hunting Creek" and "Hunting Creek Embayment" assessment areas. Geometric means that exceed the water quality criterion of 126 cfu/100mL are highlighted in red.

	2004		2005	
Month	**Upstream Hunting Creek**	**Hunting Creek Embayment**	**Upstream Hunting Creek**	**Hunting Creek Embayment**
January	57	92	90	103
February	107	112	103	99
March	91	97	102	116
April	74	104	66	110
May	106	104	60	118
June	73	116	65	106
July	99	129	93	119
August	102	119	79	106
September	84	113	56	94
October	87	103	80	121
November	90	111	77	99
December	73	102	123	105

Table C-11: Results of TMDL Scenario 10-T. Geometric means (*E. coli*), by month, for 2004 and 2005 at the "Upstream Hunting Creek" and "Hunting Creek Embayment" assessment areas. Geometric means that exceed the water quality criterion of 126 cfu/100mL are highlighted in red.

	2004		2005	
Month	**Upstream Hunting Creek**	**Hunting Creek Embayment**	**Upstream Hunting Creek**	**Hunting Creek Embayment**
January	57	92	90	102
February	107	111	103	98
March	91	96	101	113
April	74	103	65	108
May	105	102	59	114
June	71	112	65	104
July	97	123	91	115
August	101	116	78	104
September	83	111	56	94
October	87	102	80	118
November	89	108	77	98
December	72	100	123	103

Appendix D: Summary of Model Sensitivity Runs for Hunting Creek

D.1 Model Sensitivity Runs for Hunting Creek

In addition to the 10 TMDL scenario model runs that were performed for the Hunting Creek impairment (Appendix C), five "sensitivity" model runs were also performed. The purpose of these sensitivity runs was to gain a better understanding of how various sources within the Hunting Creek watershed responded to changes in model input variables, including changes of source input loadings and changes to boundary conditions. The sensitivity runs provide a broader understanding of the dynamics at play among the various sources in the Hunting Creek embayment. **Table D-1** summarizes the assumptions used for each sensitivity run. Sections D.2, D.3, D.4, and D.5 provide additional background and results for each sensitivity run.

Table D-1: Description of Model Sensitivity Runs

Scenario	Reductions in Upstream Loads (Segment 100) and Direct Drainage (Segments 120, 140, 160-180)			Reductions in Hooff Run Loads (Segment 90) and Direct Drainage (Segments 110, 130, 150, and 190)			CSO Reductions		ASA WWTP	Boundary Condition
	Human	Direct Deposition Wildlife	EOS	Human	Direct Deposition Wildlife	EOS	Outfall 002	Outfalls 003 004		
S-1	100%	50%	83%	100%	50%	98%	85%	90%	92 cfu/100mL (Fecal coliform = 63 cfu/100 ml *E.* Coli) 66 MGD flow	Source inputs set at 195 cfu/100mL (fecal coliform bacteria) Potomac decay rate = 0.0/day
S-2	100%	50%	90%	100%	50%	98%	75%	90%	195 cfu/100mL (Fecal coliform bacteria) 66 MGD flow	Source inputs set at 195 cfu/100mL (fecal coliform bacteria) Potomac decay rate = 0.0/day
S-3	100%	50%	83%	100%	50%	98%	0%	0%	Calibration flows and concentrations taken from DMRs	Dynamic: Uses Calibration Values Potomac decay rate = 0.0/day
S-4	100%	50%	83%	100%	50%	98%	0%	0%	Calibration flows and concentrations taken from DMRs	Dynamic: Uses Calibration Values Potomac Decay rate = 0.1/day
S-5	100%	50%	83%	100%	50%	98%	0%	0%	195 cfu/100mL (Fecal coliform bacteria) 66MGD flow	110 cfu/100mL (fecal coliform bacteria)

D.1.1 Description and Results for Sensitivity Run S-1.

In Sensitivity Run S-1, two sources were altered: ASA's WWTP and Alexandria's CSO Outfalls 003 and 004. The bacteria concentration from ASA's WWTP was reduced to 92 cfu/100mL of fecal coliform bacteria (roughly the equivalent of a 50% reduction of the *E. coli* bacteria geometric mean criterion of 126 cfu/100mL). It was anticipated that by reducing the bacteria concentration in the modeled effluent from ASA, but not the flow, more assimilative capacity would be available for other sources in the upper portion of the Hunting Creek impairment. Thus, the percent reduction required from COA'S CSO Outfalls 003 and 004 was reduced to 90%. The boundary condition between Hunting Creek and the Potomac River for sensitivity run S-1 was set effectively at water quality standards (195 cfu/100mL of fecal coliform bacteria). This was accomplished through:

- The concentration at the model domain boundary on the Potomac River at DCDOE monitoring stations PMS37 and PMS55 were set at a constant value of 195 cfu/ 100 ml (fecal coliform bacteria).

- The concentrations of all input sources in the extended Potomac domain were set at a constant concentration of 195 cfu/ 100 ml. These include (1) Blue Plains outfalls 001 and 002; (2) COA CSO outfall 001; (3) direct drainage from portions of Virginia outside of the Hunting Creek impairment (Segments 210 and 220); direct drainage from DC (Segment 230) and Maryland (250); and Oxon Run (Segment 240).

- The decay rate in the Potomac River was set at 0.0 /day.

The results from Sensitivity Run S-1 showed that by reducing the bacteria concentration from ASA's WWTP by roughly half, it was possible to reduce the percent reduction required from CSO Outfalls 003 and 004 from 99% to something slightly higher than 90%. Sensitivity Run S-1 did not meet water quality standards in the Upstream Hunting Creek assessment area, but it was very close. Only one month in 2005 (December) did not meet water quality standards in the Upstream Hunting Creek assessment area. **Table D-2** below shows the geometric means, by month, for 2004 and 2005 for the Upstream Hunting Creek and Hunting Creek Embayment assessment areas.

Table D-2: Results of Sensitivity Run S-1. Geometric means (*E. coli*), by month, for 2004 and 2005 at the "Upstream Hunting Creek" and "Hunting Creek Embayment" assessment areas. Geometric means that exceed the water quality criterion of 126 cfu/100mL are highlighted in red.

	2004		2005	
Month	**Upstream Hunting Creek**	**Hunting Creek Embayment**	**Upstream Hunting Creek**	**Hunting Creek Embayment**
January	45	91	89	102
February	94	104	94	97
March	83	95	101	109
April	64	99	57	104
May	104	100	64	112
June	76	109	63	101
July	121	120	109	112
August	103	115	71	102
September	83	108	42	93
October	87	100	77	118
November	94	106	66	98
December	68	98	127	103

D.1.2. Description and Results for Sensitivity Run S-2.

In Sensitivity Run S-2, two sources were altered: land based loads from the non-tidal water and the tidal watershed in model segments 100, 120, 140, 160, 170, 180; and Alexandria's CSO Outfalls 002, 003 and 004. The reductions required from the land-based loads in the non-tidal Cameron Run watershed and the tidal drainage were increased from an 83% reduction to a 90% reduction. Required reductions from the direct deposition of wildlife and human sources remained the same, at a 50% reduction and a 100% reduction, respectively. It was anticipated that by increasing the reductions required from the land based loads in the non-tidal and tidal watershed, more assimilative capacity would be available for other sources in the Hunting Creek impairment. Thus, the percent reduction required from COA'S CSO Outfall 002 was decreased to 75%, and the reduction from CSO Outfalls 003 and 004 was decreased to 90%.

The boundary condition between Hunting Creek and the Potomac River for Sensitivity Run S-2 was set effectively at water quality standards (195 cfu/100mL of fecal coliform bacteria). This was accomplished through:

- The concentration at the model domain boundary on the Potomac River at DCDOE monitoring stations PMS37 and PMS55 were set at a constant value of 195 cfu/ 100 ml (fecal coliform bacteria).

- The concentrations of all input sources in the extended Potomac domain were set at a constant concentration of 195 cfu/ 100 ml. These include (1) Blue Plains outfalls 001 and 002; (2) COA CSO outfall 001; (3) direct drainage from portions of Virginia outside of the Hunting Creek impairment (Segments 210 and 220); direct drainage from DC (Segment 230) and Maryland (250); and Oxon Run (Segment 240).

- The decay rate in the Potomac River was set at 0.0 /day.

The results from Sensitivity Run S-2 showed that by increasing the reductions required from land based loads in the non-tidal and tidal watersheds, it was possible to reduce the percent reduction required from CSO Outfalls 003 and 004 from 99% to something slightly less than 90%. Outfall 002 could be reduced from 85% to something above 75%. Sensitivity Run S-2 did not meet water quality standards in the Hunting Creek Embayment assessment area, but it did meet standards in the Upstream Hunting Creek assessment area. Only one month in 2004 (July) did not meet water quality standards in the Hunting Creek Embayment assessment area. **Table D-3** below shows the geometric means, by month, for 2004 and 2005 for the Upstream Hunting Creek and Hunting Creek Embayment assessment areas.

Table D-3: Results of Sensitivity Run S-2. Geometric means (*E. coli*), by month, for 2004 and 2005 at the "Upstream Hunting Creek" and "Hunting Creek Embayment" assessment areas. Geometric means that exceed the water quality criterion of 126 cfu/100mL are highlighted in red.

	2004		2005	
Month	**Upstream Hunting Creek**	**Hunting Creek Embayment**	**Upstream Hunting Creek**	**Hunting Creek Embayment**
January	51	97	88	108
February	85	111	81	101
March	77	101	94	118
April	63	106	59	110
May	93	108	71	123
June	83	121	72	111
July	118	135	106	123
August	98	124	76	110
September	84	116	54	99
October	84	105	79	125
November	89	116	67	104
December	68	105	104	107

D.1.3. Description and Results for Sensitivity Run S-3 and S-4.

Sensitivity Runs S-3 and S-4 were substantially different than the other TMDL and Sensitivity Runs. S-3 and S-4 were run under model calibration conditions for 2004 and 2005, except that land-based loads from the non-tidal and tidal watersheds were kept at levels necessary to meet water quality standards. Aside from reductions required from Hunting Creek watershed land based loads, no reductions were applied to bacteria sources in Maryland, D.C., or other Virginia sources not draining to Hunting Creek. These sources were modeled under their existing conditions. In addition, no reductions were applied to any of the COA's CSO outfalls. Finally, the ASA WWTP was represented in these sensitivity runs as it was under calibration conditions (i.e. the bacteria concentrations and flows for the WWTP were taken from their monthly discharge monitoring reports (DMRs). The only difference between Sensitivity Runs S-3 and S-4 is that Sensitivity Run S-3 used a decay rate in the Potomac River of 0.0 /day, and Sensitivity Run S-4 used a decay rate in the Potomac River of 0.1/day.

The purpose of Sensitivity Runs S-3 and S-4 was to try and simulate what effects the Potomac River and the COA's CSOs might have on bacteria concentrations in Hunting Creek, if it was assumed that runoff entering Hunting Creek from land-based sources in the Hunting Creek watershed was meeting standards, and if the ASA WWTP was contributing bacteria and flow under existing, current conditions. Scenarios S-3 and S-4 served the purpose of determining if reductions from COA's CSOs would be required under current conditions if upstream sources in Hunting Creek were meeting water quality standards.

In both S-3 and S-4 Hunting Creek did not meet water quality standards for many months during 2004 and 2005 in either the Upstream Hunting Creek or Hunting Creek Embayment assessment areas. By comparing the geometric means by month from Sensitivity Runs S-3 and S-4, the relative impact of increasing the decay rate in the Potomac River from 0.0/day to 0.1/day can be observed.

Tables D-4 and D-5 show the geometric means, by month, for 2004 and 2005 for the Upstream Hunting Creek and Hunting Creek Embayment assessment areas for Sensitivity Runs S-3 and S-4, respectively.

Table D-4: Results of Sensitivity Run S-3. Geometric means (*E. coli*), by month, for 2004 and 2005 at the "Upstream Hunting Creek" and "Hunting Creek Embayment" assessment areas. Geometric means that exceed the water quality criterion of 126 cfu/100mL are highlighted in red.

	2004		2005	
Month	**Upstream Hunting Creek**	**Hunting Creek Embayment**	**Upstream Hunting Creek**	**Hunting Creek Embayment**
January	37	87	137	123
February	85	104	98	100
March	96	103	157	143
April	74	117	74	120
May	159	127	127	171
June	192	169	101	132
July	326	216	317	186
August	183	164	109	124
September	132	132	36	90
October	130	112	113	163
November	168	146	71	109
December	99	121	198	127

Table D-5: Results of Sensitivity Run S-4. Geometric means (*E. coli*), by month, for 2004 and 2005 at the "Upstream Hunting Creek" and "Hunting Creek Embayment" assessment areas. Geometric means that exceed the water quality criterion of 126 cfu/100mL are highlighted in red.

	2004		2005	
Month	**Upstream Hunting Creek**	**Hunting Creek Embayment**	**Upstream Hunting Creek**	**Hunting Creek Embayment**
January	36	81	136	117
February	85	98	98	95
March	95	97	156	137
April	74	113	74	117
May	158	119	125	166
June	191	162	99	125
July	324	208	316	181
August	181	158	108	119
September	131	128	35	85
October	129	109	112	155
November	167	140	70	102
December	98	114	198	120

D.1.4. Description and Results for Sensitivity Run S-5.

In Sensitivity Run S-5, the key variable that was altered was the boundary condition between Hunting Creek and the Potomac River. All land-based sources from the non-tidal Cameron Run and tidal Hunting Creek watershed were kept at levels necessary to meet water quality standards. The ASA WWTP was represented in the model at a concentration of 195 cfu/100mL (fecal coliform bacteria) and a design flow of 66 MGD. No reductions were required from the COA CSS.

The boundary condition between Hunting Creek and the Potomac River was set effectively at 110 cfu/100mL of fecal coliform bacteria. This is roughly equivalent to the *E. coli* geometric mean of 74 cfu/100mL. 74 cfu/100mL of *E. coli* is the approximate long-term, observed, geometric mean at Station PMS44. The boundary was set by having all Potomac River bacteria sources set at 110 cfu/100mL of fecal coliform bacteria, along with the northern and southern boundaries of the model domain. In addition, a decay rate of 0.0 was used in the Potomac River.

The purpose of this run was to examine the effects of the COA CSO when using a lower boundary condition. The results from Sensitivity Run S-5 show that by decreasing the boundary to 110 cfu/100mL, and having all other sources (aside from the CSOs) discharging at or below water quality standards, water quality standards are still not met in Hunting Creek.

Table D-6 shows the geometric means, by month, for 2004 and 2005 for the Upstream Hunting Creek and Hunting Creek Embayment assessment areas for Sensitivity Run S-5.

Table D-6: Results of Sensitivity Run S-5. Geometric means (*E. coli*), by month, for 2004 and 2005 at the "Upstream Hunting Creek" and "Hunting Creek Embayment" assessment areas. Geometric means that exceed the water quality criterion of 126 cfu/100mL are highlighted in red.

	2004		2005	
Month	**Upstream Hunting Creek**	**Hunting Creek Embayment**	**Upstream Hunting Creek**	**Hunting Creek Embayment**
January	55	67	157	98
February	117	97	114	79
March	115	83	182	118
April	93	95	96	95
May	177	103	153	137
June	208	139	133	107
July	341	181	319	152
August	200	133	128	98
September	150	100	55	66
October	145	84	140	135
November	180	115	92	85
December	116	97	207	102

References

American Veterinary Medical Association. 2007. U. S. Pet Ownership and Demographics Sourcebook.

Baptista, A. M., Y. Zhang, A. Chawala, M. Zulauf, C. Seaton, E. P. Meyers III, J. Kindle, M. Wilkin, M. Burla, and P. J. Turner. 2005. A cross-scale model for 3D baroclinic circulation in estuary-plume-shelf systems: II. Application to the Columbia River. Continental Shelf Research

Bennett, K. 2009. Stormwater Planning Division. Fairfax County Department of Public Works and Environmental Services. Personal communication.

Bicknell, B.R., J.C. Imhoff, J.L. Kittle, Jr., and A.S. Donigian, Jr. 2000. Hydrological Simulation Program - Fortran (HSPF): User's Manual for Release 12.

Camp, Dresser, and McGee. 2003. Stormwater Model and GIS Interface Guidelines. Technical Memorandum, County of Fairfax Department of Public Works and Environmental Services Stormwater Planning Division.

Casulli, V., Cattani, E., 1994. Stability, accuracy and efficiency of a semi-implicit method for 3D shallow water flow. Computers & Mathematics with Applications 27, 99–112.

Casulli, V., Zanolli, P., 1998. A three-dimensional semi-implicit algorithm for environmental flows on unstructured grids Institute for Computational Fluid Dynamics Conference on Numerical Methods for Fluid Dynamics VI.

Casulli, V., and Zanolli, P. 2005. High resolution methods for multidimensional advection-diffusion problems in free-surface hydrodynamics.. *Ocean Model.*, 10(1–2): 137–151.

Cerco C. F. and A. Y. Kuo, 1983. Water quality in a Virginia Potomac embayment Hunting Creek – Cameron Run.   Special Report no. 244 in Applied Marine Science and Ocean Engineering, Virginia Institute of Marine Science.

Cerco, C. F. and T. Cole. 1995. User's Guide to the CE-QUAL-ICM Three-Dimensional Eutrophication Model: Release Version 1.0. Technical Report No. EL-95-15, U. S. Army Corps of Engineers, Waterways Experiment Station. Vicksburg, MS.

Cho, K-H. 2008. A numerical modeling study of barotopic and barolcinc responses of the Chesapeake Bay to Hurricane Events. Ph.D. thesis, Virginia Institute of Marine Science, College of William and Mary, 284 pp.

City of Alexandria. 2001. City of Alexandria Master Plan: Water Quality Supplement. Alexandria, VA.

Douherty, John. 2000. PEST: Model-Independent Parameter Estimation. Watermark Numerical Computing.

Feld, D. 2009. Geese Peace. Personal Communication.

Finerfrock, B. 2009. Virginia Department of Transportation. Personal communication.

Flater,D.2005. XTide. http://www.flaterco.com/xtide/.

Grant, D. 2009. Lake Barcroft Watershed Improvement District. Personal communication.

Horseley and Whitten, Inc. 1996. Identification and Evaluation of Nutrient Bacterial Loadings to Maquiot Bay, Brunswick and Freeport, Maine.

Joye, A. 2009. Fairfax County Health Department. Personal communication.

Kahn, S. 2009. City of Falls Church. Personal communication.

Kanzler, J. 2009. City of Alexandria. Personal communication.

Keulegan, G. H. (1967). "Tidal Flow in Entrances Water-Level Fluctuations of Basins in Communications with Seas," Technical Bulletin No. 14, Committee on Tidal Hydraulics, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Limno-Tech Inc.2008. Partial Documentation of the Development and Application Receiving Waters Models in Alexandria, VA. Washington, DC.

Loftis, J.,and H.Wang. 2010. Comparing Numerical and Alalytical Solution for Fecal Coliform Concentration with Ideal Test Case in Hunting Creek, Potomac River. (in preparation).

Moyer, D.L., and M. R. Bennett. 2007. Development of relations of stream stage to channel geometry and discharge for stream segments simulated with Hydrologic Simulation Program-Fortran (HSPF), Chesapeake Bay Watershed and adjacent parts of Virginia, Maryland, and Delaware. U.S. Geological Survey Scientific Investigations Report 2007-5135.

Moyer, D. L. and K. E. Hyer. 2003. Use of the Hydrological Simulation Program–FORTRAN and Bacterial Source Tracking for Development of the Fecal Coliform Total Maximum Daily Load (TMDL) for Accotink Creek, Fairfax County, Virginia. U. S. Geological Survey Water Resources Investigations Report 03-4160.

National Geophysical Data Center, National Ocean and Atmospheric Administration, US Department of Commerce (2002): Geophysical Data System (GEODAS), NGDC Coastal Relief Model.

Smith, C. 2009. Fairfax County Park Authority. Personal communication.

Thomas, C. M. 2009. U. S. Army Corps of Engineers, North Atlantic Division. Personal communication.

Umlauf, L., Burchard, H., 2003. A generic length-scale equation for geophysical turbulence models. Journal of Marine Research 6 (12), 235–265.

U. S. Army Corps of Engineers (USACE). 2007. Hydrologic and Hydraulic Analysis for the Cameron Run Watershed in Northern Virginia. USACE, Baltimore District.

U. S. Census Bureau. 2008. Washington, DC. http://www.census.gov.

U. S. Department of Transportation, Federal Highway Administration. 2004. Tidal Hydrology, Hydraulics and Scour at Bridges. First Edition. publication no. FHWA-NHI-05-077, Hydraulic Engineering Circular no. 25.

U.S. Environmental Protection Agency (EPA). 1985. Rates, Constants, and Kinetics formulations in Surface Water Quality Modeling. Athens, GA.

U.S. Environmental Protection Agency (EPA). 2001a. Better Assessment Science Integrating Point and Nonpoint Sources (BASINS), Version 3 Washington, DC.

U.S. Environmental Protection Agency (EPA). 2001b. EPA 841-R-00-002. Protocols for developing Pathogen TMDLs. Available at <http://www.epa.gov/owow/tmdl/pathogen_all.pdf >

U.S. Environmental Protection Agency. 2002. Wastewater Technology Factsheet: Bacterial Source Tracking. http://www.epa.gov/owm/mtb/bacsortk.pdf

U.S. Environmental Protection Agency (EPA). 2005. "Overview or Current Total Maximum Daily Load (TMDL) Program and Regulations." Available at <http://www.epa.gov/owow/tmdl/overviewfs.html > Website visited August, 2005.

U.S. Environmental Protection Agency. 2005b. Microbial Source Tracking Guide Document. http://www.epa.gov/nrmrl/pubs/600r05064/600r05064.pdf

U.S. Department of Agriculture, Natural Resource Conservation Service (NRCS). 2000. STATSGO Soils Browser CD-ROM Version 1.0. February 2000.

Versar, Inc. 2007. Modeling Report: Cameron Run Watershed Plan (Appendix B). Columbia, MD.

Virginia Cooperative Extension. 2009. Microbial Source tracking and the TMDL (Total Maximum Daily Loads) Process. Virginia Cooperative Extension Publication 442-554. http://pubs.ext.vt.edu/author/h/hagedorn-charles-res.htm

Virginia. *State Water Control Board.* 2006. 9 VAC 25-260. Virginia Water Quality Standards. Available at <http://www.deq.virginia.gov/wqs.html >

Virginia Department of Environmental Quality (VADEQ). 1998. *1998 Water Quality Assessment Report, Part III Surface Water Monitoring.* Available at <

http://www.deq.state.va.us/wqa/305b1998.html>

Virginia Department of Environmental Quality (VADEQ). 2000. *Total Maximum Daily Load Program, A Ten Year Implementation Plan-Report to the Governor, House Committees, and Senate Committees, November 1, 2000.* Available at <http://www.deq.state.va.us/tmdl/reports/hb30.pdf>

Virginia Department of Environmental Quality (VADEQ). 2002. 2002 *Water Quality Assessment Report, Part III Surface Water Monitoring.* Available at <http://www.deq.state.va.us/wqa/305b.html>

Virginia Department of Environmental Quality (VADEQ). 2003. *Guidance Manual for Total Maximum Daily Load Implementation Plans.* Available at <http://www.deq.state.va.us/tmdl/implans/ipguide.pdf >

Virginia Department of Environmental Quality (VADEQ). 2003. *Guidance Memo No. 03-2012 HSPF model Calibration and Verification for Bacteria TMDLs*.

Virginia Department of Environmental Quality (VADEQ). 2004a. 2004a 305(b)/303(d) *Water Quality Assessment Integrated Report, (draft).* Available at <http://www.deq.state.va.us/wqa/305b2004.html>

Virginia Department of Environmental Quality (VADEQ). 2004b. "Total Maximum Daily Loads, Background-Legal and Regulatory Framework." Available at <http://www.deq.state.va.us/tmdl/backgr.html>

Virginia Department of Environmental Quality (VADEQ). 2005. "Total Maximum Daily Loads." Available at <http://www.deq.state.va.us/tmdl>

Virginia Department of Environmental Quality (VADEQ). 2006. Final 2006 305(b)/303(d) *Water Quality Assessment Integrated Report.* Available at <http://www.deq.state.va.us/wqa/ir2006.html>

Virginia Department of Environmental Quality (VADEQ). 2007. Bacteria TMDL for Neabsco Creek Prince William County, Virginia. Available at <http://www.deq.virginia.gov/tmdl/apptmdls/potrvr/neabsco.pdf>

Virginia Department of Environmental Quality (VADEQ). 2008. Final 2008 305(b)/303(d) *Water Quality Assessment Integrated Report.* Available at <http://www.deq.state.va.us/wqa/ir2008.html>

Virginia Department of Environmental Quality (VADEQ). 2008b. Total Maximum Daily Load Development for the James River —Hopewell to Westover. Available at <http://www.deq.virginia.gov/tmdl/apptmdls/ jamesrvr/jmsbail.pdf>

Virginia Department of Environmental Quality (VADEQ). 2008c. Bacteria TMDL for Lower Accotink Creek Fairfax County, Virginia. Available at <http://www.deq.virginia.gov/tmdl/apptmdls/potrvr/ accotinkec.pdf>

Virginia Department of Environmental Quality (VADEQ). 2010. Bacterial Total Maximum Daily Load Development for the James River and Tributaries—City of Richmond. Available at <http://www.deq.virginia.gov/tmdl/apptmdls/ drftmdls/jamesg3.pdf>

Wang, C-F., H. V. Wang, and A. Kuo .2008. Mass Conservative Transport Scheme for the Application of the ELCIRC Model to Water Quality Computation. Journal of Hydraulic Engineering.134:1166-1171.

WXTide32. 2010. http://www.wxtide32.com/

Zhang, Y.-L., Baptista, A.M. and Myers, E.P. 2004 A cross-scale model for 3D baroclinic circulation in estuary-plume-shelf systems: I. Formulation and skill assessment. Cont. Shelf Res. 24: 2187-2214.